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# **SIMULATORS FOR MARINER TRAINING AND LICENSING**

## **PHASE 1: THE ROLE OF SIMULATORS IN THE MARINER TRAINING AND LICENSING PROCESS**

**VOLUME I**



JULY 1980

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**CAORF TECHNICAL REPORT  
SIMULATION EXPERIMENT**

**SIMULATORS FOR MARINER  
TRAINING AND LICENCING  
PHASE I: ROLE OF SIMULATORS  
IN THE MARINER TRAINING  
AND LICENSING PROCESS**

**VOLUME I**

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**DEPARTMENT OF COMMERCE**

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## PREFACE

This document reports on the initial phase of a multiphase effort investigating the role of simulators in the mariner training and licensing process. The long-term goal of the project is to establish criteria of simulator training for partial satisfaction of some license requirements.

The initial phase of the project has been directed toward the development of an effective investigative methodology, development of a comprehensive information base pertaining to mariner behavior and training system design, and the identification of knowledge gaps for the direction of subsequent empirical research. The second phase (of approximately 1 year duration) has embarked on an empirical investigation to specify key issues in simulator and training curricula design. The key issues (e.g., simulator visual field of view) will be objectively evaluated via simulator-based experimentation using experienced mariners. The third phase will bring the subset of issues investigated to conclusion. This is expected to be accomplished by the conduct of an at-sea transfer of training investigation. Simulator-based experimentation is expected to continue to further refine and/or expand the results. These three phases will result in the development of the criteria as noted above. The draft report is expected to be completed by June 1981.

A clarification and summary of important points in this Phase 1 research follows.

## METHODOLOGY CONSIDERATIONS

This project, as its title proclaims, was explicitly concerned with the analysis of the role of the bridge/shiphandling simulator in the mariner training and licensing process. The essence of the several Phase 1 objectives was an attempt to compile the currently available information relevant to the use of a bridge/shiphandling simulator for mariner training, and to identify gaps in the knowledge pertaining to the development and use of the simulator for training and licensing. Several important considerations regarding this investigation were:

- The investigation focused on the masters level mariner. The specific functional objectives, and subsequent project results stemming from them, pertain to the masters level mariners. Pilots and other levels of deck officers were not specifically addressed during this phase, although the results may be partially applicable to them in varying degrees.
- The investigation focused on the role of the bridge/shiphandling simulator, as one of several elements in the training system. This study did, however, recognize other elements of the training system and their interface with the simulator (i.e., classroom, at-sea training/experience, instructor and trainee guides, and part-task trainers). Additionally, considerable emphasis was placed on those elements of the training system that can greatly affect the training effectiveness of the simulator (e.g., curricula structure and content, specific functional objectives, performance measures, and training technology). Furthermore, it should be recognized that the cost effective training system draws upon a mix of elements in achieving its specific training objectives; the simulator cannot be dealt with separate from the total training system, but rather, must be integrated with the other elements.

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- The set of specific functional objectives which guided the investigation of the simulator and other training system elements was developed from four independent deck officer task analyses. These task analyses were previously developed from at-sea investigation. They were integrated during the present investigation to yield a comprehensive set of deck officer tasks. The set of tasks and the resultant set of specific functional objectives pertain to those deck officer skills performed on the bridge.
- Considerable research and operational experience pertaining to simulator-based training systems has been accomplished by other industries (e.g., commercial aviation, nuclear power generation, Navy, Air Force). This available information, which represents a considerable research investment, was used as the starting point for this investigation of simulators in the maritime industry. Although the specific requirements of the maritime industry are, of course, unique (e.g., deck officers tasks are predominantly decisionmaking in nature), and may often differ widely from the training needs in other industries, the investigative methodologies used by these other industries pertain to simulator-based training systems and were of great use in developing the methodology. Furthermore, the experiences of these industries interfacing with labor, operators, and regulatory bodies was of value.
- The investigation, as noted above, focused on the simulator and those deck officer skills which may be amenable to simulator training. Other areas of deck officer training and/or experience (e.g., shipboard management) exist and were obviously not addressed by this effort since those areas were not amenable to training on a bridge/shiphandling trainer. It is recognized that these other areas are important for the training of masters. Furthermore, it should be noted that this study does not imply that the simulator should be a substitute for at-sea experience. At-sea experience is recognized as an important component of mariner skill acquisition. Finally, simulators may be effective for other areas of mariner training which also were not addressed by this investigation (e.g., cargo handling, engine room operation).

## RESULTS SUMMARY

The Phase 1 report is broad, covering a wide variety of areas relevant to simulator-based training in the maritime industry. Several of the more important results are noted below.

- The systems approach to training methodology was adapted and used for this investigation. This basic methodology, which was developed by the U.S. Air Force and U.S. Navy, has been applied extensively to the investigation and design of simulator-based training systems. It was adapted with regard to the specific issues surrounding deck officer training. Aspects of this investigation included specific functional objectives, performance measures, training technology, and simulator characteristics.
- An extensive information base was compiled pertaining to (1) deck officer behavior, (2) training technology, (3) ship/bridge simulators, and (4) mariner training programs.
- A set of 74 possible specific functional objectives (i.e., training objectives) were developed for consideration of achievement via simulator training. These

SFOs addressed five major categories of deck officer skill: (1) fundamental shiphandling, (2) integrated shiphandling, (3) emergency shiphandling, (4) team coordination and communications, and (5) bridge procedures. These represent the goals of the deck officer training system which may be achievable via simulator-based training.

- A generalized training program framework was developed to achieve the specific functional objectives. This framework consisted of 12 training modules, each addressing different areas of training. These constitute the training program guidelines for the establishment of simulator-based deck officer training. The concept of tailoring training to the specific needs of individuals was put forth in the context of the diagnostic analysis scenario.
- A detailed set of bridge/shiphandling characteristics were identified, with alternative methods for their accomplishment contrasted. Furthermore, the capabilities and limitations of each alternative simulator characteristic were developed with regard to achieving each of the 74 specific functional objectives.
- Technology limitations common to most computer-driven bridge/shiphandling simulators were summarized.
- Gaps in the existing knowledge regarding the design, operation and use of simulators in the maritime industry were identified. These represent the research issues for future investigation.
- The majority of the specific functional objectives (i.e., 71 of the 74) were determined by the project team to be better achievable via simulator-based training than on-the-job training. This finding points to the potential of simulator-based training for deck officer skills concerned with bridge operation and shiphandling.
- A wide variety of performance measures were identified. This, however, represents a major area of required investigation; performance measures are essential to the conduct and evaluation of a training process.

## INDUSTRY REVIEW

A preliminary draft of this report was distributed to a variety of individuals and organizations in the international maritime community for their review and comment. Specific responses were requested regarding prioritization of training modules and simulator design characteristics, an analysis of which will be presented in a separate report. Additionally, comments were solicited regarding all aspects of the study to provide information which would assist the researchers in the correction and clarification of this report, and influence the sponsors and Advisory Group in their consideration of future project direction. Comments were carefully examined by project researchers and sponsors for relevance, representativeness, and accuracy. It was decided that those comments which proceeded from a specific criticism or misunderstanding of the report would be addressed through revision of text and, where most appropriate, clarification by means of this preface. Comments which pertain to issues beyond the scope of this report will be addressed in a separate report.

Researchers and sponsors of the study would like to extend their thanks for the interest shown in the report and the constructive comments of those individuals and organizations who participated in the prepublication review:

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## CHAPTER 1

### INTRODUCTION

#### 1.1 BACKGROUND

National and international concern regarding the safety of merchant vessels, crews, and cargoes has been increasing substantially in recent years. This concern has focused on the major areas contributing to ship safety: hull design, control system design, instrumentation, training, crew qualifications, and regulations. This concern is evidenced, for example, by recent international agreements as seen in the Inter-Governmental Maritime Consultative Organization (IMCO) meeting on standards of training and watchkeeping, and the Tanker Safety Pollution Prevention Conference, both held in 1978. This increasing concern is due to a variety of factors. The size of vessels has steadily increased over the years; port design and modification has generally not kept pace. The size of the largest ships afloat today exceed 500,000 dead weight tons (dwt), as compared with a maximum size of 6,000 dwt 50 years ago (Shipley, 1977). The allowable margin of error in maneuvering a vessel has thus been reduced as vessel size has increased. The nature of cargo carried has also undergone change, with an increasingly large proportion of vessels carrying hazardous cargo. In many instances the larger vessels are carrying the hazardous cargoes (i.e., Very Large Crude Carriers; Liquified Natural Gas carriers). These circumstances result in an increasing potential for catastrophic consequences to man and the environment if an accident should occur (Maritime Transportation Research Board, 1976). The increasing investment value of the ship and cargo further underlines this concern. These factors, which are based on evolving changes in the maritime industry, lead to a concern for similar improvements in ship control and ultimately safety.

Marine casualties have steadily increased in numbers, cost, and impact on the environment. The annual tonnage loss has steadily increased over the past 15 years. About 125 ships were lost in 1962, representing about 525,000 gross tons; this statistic has increased to slightly more than 200 ships in 1977, representing more than 1,200,000 gross tons (Liverpool Underwriters Association, 1977). Although the steady increase in tonnage lost due to accidents may be the result of a variety of factors, the increasing potential for damage as a result of these accidents has given impetus to efforts to take corrective actions. The grounding of the Argo Merchant on the Nantucket Shoals was a major catalyst leading to President Carter's call for improved ship design and improved licensing and qualification standards of mariners. The more recent collision of the Venpet and Venoil off the African coast, and the grounding of the Amoco Cadiz off the French coast have further highlighted the international concern for maritime safety. Investigations of maritime accidents have generally supported two major conclusions. First, the majority of accidents (i.e., collisions, ramblings, and groundings) have occurred in restricted waterways (i.e., harbors and approach waters, including rivers and bays) (e.g., Cordell and Nutter, 1976). Second, human error is a major contributory factor in more than 80 percent of the accidents (e.g., American Hull Insurance Syndicate, 1972; Cordell and Nutter, 1976; Hooft, Keith, and Porricelli, 1975; Stoeher, Morgan, Beuffler, and Tuller, 1977). These factors underlie the growing concern regarding the capabilities with which mariners handle their vessels.

The above factors have not passed unnoticed by the maritime community. Responsible ship operators, labor organizations, and schools/academies have continuously striven to improve the capabilities of the mariner and the vessel. This is evidenced by close participation in the achievement of international agreements pertaining to training, manning, ship design, rules of the road, bridge operations, and instrumentation. Continued

progress in each of these areas is necessary to improve maritime safety. Regulatory bodies have also had a major impact on mariner proficiency by continuously raising qualification standards. One such example is the present consideration being given in the United States to a requirement for skill demonstration on a radar simulator prior to obtaining the radar endorsement. The recent (1978) IMCO convention, which has adopted a set of standards specifying minimum training requirements for shipboard positions, is an example of close cooperation among all interested parties. Nevertheless, substantial improvements in marine proficiency may still be obtained through improved training effectiveness. The long-term goal of this project is to establish criteria of simulator training for partial satisfaction of some license requirements.

Ship masters, to obtain new or renewal licenses, are required to demonstrate their knowledge pertaining to the handling of a vessel through a written test. They do not, however, have to demonstrate their skill in the handling of a vessel. The specific shiphandling skill a master possesses typically depends on his experience at sea, which may vary greatly among masters. For example, it is reasonable to assume that many masters have not been exposed to the range of emergencies at sea that they may have to encounter some day. The technology is now available, in the form of simulation, to provide extensive training/experience in many aspects of shiphandling under completely safe conditions. The current availability of shiphandling simulators for training, however, is somewhat limited. This is particularly true in the United States where only one is currently available for commercial training.

Simulation technology has had a substantial impact on training in general, and appears to have great potential in the maritime field. The Navy, Air Force, and Army, as well as the commercial aviation and power generation industries, have made extensive use of simulation for the training of personnel. The use of simulation in maritime training is not new; simulators are accepted and have been used successfully in the maritime industry for training. The radar endorsement, in particular, has usually been awarded as the result of a training program using a radar simulator. The use of simulation in maritime training has been rapidly increasing in recent years due to the technological availability of acceptable visual scene simulation. The visual scene, which typically represents the largest proportion of cost for a ship bridge simulator, is the primary distinguishing characteristic among the nearly two dozen operational, or planned, ship bridge simulators around the world. The ship bridge simulator can provide training in the wheelhouse environment with a variety of information sources and controls (e.g., visual scene, radar, radio communications, traffic vessels, and own ship control). Substantial improvement in mariner skill may be possible through widespread use of simulation.

## 1.2 THE USE OF TRAINING SIMULATORS IN INDUSTRY

The use of simulators in industry has been growing over the past several decades. Simulators, from the early WW II days when aircraft were in short supply, through the period of aerospace vehicle testing in the 1960's, to commercial use today, have played a major part in ensuring high operator competence and safety while reducing costs.

Simulation, with little doubt, has contributed significantly to improving overall flight safety in the aviation industry (*Safety Record of U. S. Scheduled Airlines, 1930 - 1970, NTSB*) and to the marked success of NASA manned space projects. Approximately 90 percent of all commercial aviation accidents and near-misses which do occur are attributed to human error during the take-off, approach, and landing phases of flight. This represents the period of highest operator workload and man-machine interface, and is quite synonymous with restricted water operations in the maritime industry. More

effective use has been made of the aircraft simulator in both training and checking of flight crew members. The increasing size, complexity, and operating costs of the modern turbojet transport and its operating environment as well as problems of safety (e.g., San Diego airline crash which occurred on September 25, 1978 involving a student pilot - flown Cessna 172 and a PSA 727) point to greater use of the advanced technology which is now available in aircraft simulators. Airlines believe that by exposing their personnel to simulated emergency situations unattainable or impractical in real aircraft, a majority of even these accidents could be prevented. "Simulators can provide more in-depth training than can be accomplished in the aircraft" (Federal Aviation Administration, 1978). Furthermore, the FAA states that "a very high percentage of transfer of learning occurs from the simulator to the aircraft", and "the ultimate goal is 100 percent transfer at which time all training and checking could be accomplished in the simulator" (Federal Aviation Administration, 1978). Recent Federal Aviation Requirements (FAR) amendments have permitted a simulator approved for the landing maneuver to be substituted for the aircraft in a pilot recency of experience qualification. These changes to the FAR constituted a significant step toward the optimum use of aircraft simulators in flight training and checking.

The aviation industry uses the simulator as an integral part of its training and licensing process. The use of simulators for training and licensing is largely regulated by the FAA. Pilots and copilots, to maintain their certification, receive periodic recurrent training and proficiency checks on simulators. Simulators are also used for "upgrading" in position (e.g., from second in command to captain); "transition" training to new aircraft (e.g., transfer to a new airplane); and "differences" (e.g., new variation of same airplane) training programs. The aviation simulators are periodically inspected and certified by the FAA to ensure their effectiveness in the particular training or qualification role (Code of Federal Regulations, Part 121, Title 14, 1976). TABLE 1 illustrates the increasing trend to use simulators rather than actual aircraft for certification. Inspection of the table reveals that for the DC-8 transition training involved, the number of maneuvers in the actual aircraft has been reduced from 43 to 5 over the past eight years.

A salient feature which has guided the progression shown in TABLE 1 was the application of "specific behavioral objectives" to the development of training and certification programs for the aviation industry. This technique was jointly applied by United and American Airlines (1977) in an effort to systematically assure themselves and the FAA that training/certification programs adequately address all critical pilot behaviors for both normal and emergency situations. These objectives resulted from a behavioral task analysis conducted for an industry program involving pilots and FAA participation. This same methodology of conducting a task analysis was used to establish the behavioral data base for this project. One result of this project, the identification of specific functional objectives for normal and emergency ship handling to be achieved by the master as a result of a particular training program, is quite synonymous with the technique employed by the aviation industry.

The nuclear power generation industry has recently been making extensive use of simulators in training and requalification programs for reactor operators and key plant personnel. Utility managers are presently faced with the major dilemma of rapidly training and qualifying large numbers of highly skilled reactor operators. Factors relating to safety, economics, and training effectiveness have influenced their decisions. The Nuclear Regulatory Commission (NRC) has recognized the effectiveness of nuclear power plant simulator-based training programs by awarding credit on a three-for-one time basis for such use. That is, up to one year of training (four months on a simulator) is accepted in lieu of plant experience in qualifying for initial licensing (Hughes and O'Halloran, 1974). This policy recognizes a practical distinction between on-the-job training, experience, and simulator-based training.

**TABLE 1. MANEUVERS REQUIRED TO BE SATISFACTORILY PERFORMED  
IN SIMULATOR DURING DC-8 CAPTAIN TRANSITION**

	2/69	11/70	'74	'77
Prestart and start procedures		X	X	X
Taxiing				
Normal instrument take-off (normal instrument)		X	X	X
Engine failure take-off			X	X
Rejected take-off				X
Climbing turns				
Normal		X	X	X
Engine inoperative		X	X	X
Lateral control		X	X	X
Tuck and mach buffet		X	X	X
Runaway stabilizer		X	X	X
Jammed stabilizer		X	X	X
Approach to stalls		X	X	X
Flight characteristics		X	X	X
Steep turns		X	X	X
Cruise control		X	X	X
Emergency descent		X	X	X
Areas arrival and departure		X	X	X
Use of navigation and communication				
Equipment		X	X	X
Holding		X	X	X
Flt. dir. ILS approach				
Normal				
Engine inoperative				X
Autopilot		X	X	X
Non-precision approach				
VOR		X	X	X
ADF		X	X	X
Bkse		X	X	X
Circle			X	X
Missed approaches				
ILS				X
Engine inoperative			X	X
Non-precision		X	X	X
Landings				
Normal VFR				
From ILS				X
1 engine inoperative				
2 engines inoperative			X	X
Zero flap			X	X
Rejected				X
Stablizer out of trim		X	X	X
Engine fire				
Air		X	X	X
Ground		X	X	X
Manual flight control approach				X
Engine(s) out maneuvering		X	X	X
First officer duties		X	X	X
Engine shut down and relight		X	X	X
<b>TOTAL</b>	<b>0</b>	<b>27</b>	<b>32</b>	<b>38</b>



The power generation industry also uses simulators for requalification of senior reactor operators and for refresher training. Initial qualification of reactor operators, who usually come from the United States Navy, may occur via a combination of participatory assignments at operating reactors and/or suitable reactor simulators. The effectiveness of training nuclear operators for the U. S. Savannah was attributed, in part, to the program's comprehensive simulation (Gross, 1973).

NASA and the aerospace industry have relied almost totally upon simulation training. Although airborne simulators are utilized to a large extent in advanced development systems, ground simulation remains the most cost-effective method for basic skill development. To fly prototype aircraft, NASA pilots are frequently compelled to train and qualify solely through the use of simulation, but only after basic airborne training qualification.

In the past, the maritime industry has made relatively little use of simulation. However, due to the increasing size and speed of vessels, the increased proportion of dangerous goods being transported, and the increased damage potential as a result of collisions, rammings, groundings and other accidents, simulator-based training may be desirable. Radar simulators, which represent one type of part task simulator, have been used in increasing numbers in nautical colleges since the late 1950's as a tool for training instrument navigation and collision avoidance. Radar simulators presently exist in the maritime training institutions of many countries. Shiphandling simulators however, are relatively new. The first ship handling simulator, Port Revel, the Marine Research and Training Center, was built in 1967 and uses the scale model method of training on an 8-acre lake. The first land-based simulators, the Ship Maneuvering and Research Simulator (Institute TNO for Mechanical Constructions) and the Netherlands Ship Model Basin Simulator were first operational in 1968 and 1969, respectively. Since 1975, with the availability of new technology (i.e., computer generated imagery), maritime use of simulators has shown rapid growth. As can be seen from TABLE 2, operational simulators have more than doubled in the past three years. There is still a relatively small percentage of maritime simulator usage; however, as indicated by this table, the demand and the use of simulators is on the rise.

### 1.3 MARITIME TRAINING AND SIMULATION

The underlying philosophy for training and licensing of United States deck officers evolves primarily from achieving competence through experience. On-the-job training conducted throughout the United States merchant marine varies widely in discipline and technique depending upon company policy, interest, instructional ability of senior officers, ship characteristics, and trade route. Advancement through the officer ranks is controlled by time in grade and government-administered examinations. The examinations are theoretical in nature and require little practical demonstration of skills or proficiency other than radar plotting. United States marine licenses are renewed periodically, based solely upon the officer's recent "ship-related" service, a physical examination, and his cognizance of recent changes to the "rules". The license in itself does not ensure shiphandling competency.

Although graduates of the many accredited maritime academies approach their first assignment with ample knowledge, few have had the opportunity to apply the manipulatory trial-and-error tasks vital to the development of skills. Ship operators, largely through union training programs, have conducted training through the application of part-task simulators. However, the majority of the junior officer's training is the responsibility of senior officers and the master on board the vessel. For the apprentice marine pilot, training is conducted by the working pilot.

**TABLE 2. CHRONOLOGY OF WORLD SIMULATORS**

NAME OF SIMULATOR	DATE OPERATIONAL
Port Revel	1967
The Ship Maneuvering and Research Simulator of the Institute TNO for Mechanical Constructions, Delft	1968
Netherlands Ship Model Basin Simulator, Wageningen	1969
Swedish State Shipbuilding Experimental Tank (SSPA)	1967
SR151 Ship Maneuvering Simulator	1975
Bremen Nautical Academy, Ship Handling Simulator	1975
Marine Safety International (MSI)	1976
Ishikawajima-Harima Heavy Industries, Co., Ltd (IHI)	1975
Computer Aided Operations Research Facility (CAORF)	1976
Institute for Perception - TNO, Soesterberg	1976
College of Nautical Studies, Warsash (Near Southampton)	1976
Navigation Simulator System, Tokyo University of Mercantile Marine	1976
Steering Simulator, University of Hiroshima	1971
Bremen Nautical Academy, Navigation Lights Simulator	1978
Solartron Schlumberger	1971
Marconi Radar Systems Ltd.	1972

Schumacker, Madsen, and Nicastro (1972) have suggested the following improvements to the current regulations:

- "A. Performance testing of some sort under both normal and stress conditions prior to issuing a license.
- B. Periodic proficiency checks to maintain a license.
- C. Some restriction as to size and class of ship the individual is licensed to operate. Both written and performance examinations would vary to demonstrate handling proficiency and competence.
- D. The curriculum of maritime training academies should be reviewed to ensure that up-to-date instruction is being given in such things as shiphandling and maneuvering, navigation and collision avoidance. (Note: This recommendation is currently being carried out.)
- E. Some formal training should be required before an officer can advance in grade. For example, this could take the form of simulator, navigation and/or collision avoidance training.
- F. Some form of periodic, recurrent training should also be required to validate licenses. This again could take the form of simulator training, or perhaps at sea, shipboard training exercises in maneuvering and even collision avoidance via video tape."

Schumacker et al further state "the effective monitoring of performance and testing of proficiency is perhaps critical to improving maritime safety performance. It would appear desirable to make proficiency testing part of the licensing requirements with periodic retesting required to maintain the license." This view, although not predominant, has some adherence in the maritime community as a result of the factors noted earlier by the Committee of Inquiry into British Shipping (Rochdale, 1972).

Considerable information has been developed regarding the design and use of simulators. The vast majority of this information pertains to (a) general design and use methodologies, technology, and principles; and (b) specific applications (e.g., aircraft pilot training). Relatively little objective information is available that pertains to the design and use of maritime simulators for training. The factors of particular interest concern the relative cost effectiveness of simulator characteristics and other training program characteristics for specific areas of training. Relevant issues include the design and operating cost, the skills amenable to simulator-based training, the effectiveness of simulator-based training compared with other modes of skill acquisition, the retention of skills, and the capabilities and limitations of simulator characteristics.

The areas of possible application of simulation for maritime training vary widely (e.g., deck officer in the wheelhouse, cargo handling, engine room). The wheelhouse area, impacting the various aspects of ship control, has received considerable attention to date. Ship bridge simulators used throughout the world for training employ a wide variety of techniques. The Grenoble approach, for example, uses 1/25 scale ship models maneuvering in a lake under a variety of conditions. A vastly different approach is represented by the CAORF simulator, which is a land-based bridge with a variety of computer generated conditions. These simulators, and the many others like them, provide masters, mates, and pilots the opportunity for realistic shiphandling under a variety of operating conditions, vessel designs, and environments. The skill areas amenable to training on a ship bridge simulator may vary widely, depending on a variety of simulator, training, and task factors. Watson and Stewart (1975) suggest four areas: (a) ship maneuvering (e.g., coming up to

anchor), (b) collision avoidance, (c) coastal navigation, and (d) added impositions (e.g., reduced visibility and system failures). Steele and Hansford (1976) specify shiphandling and collision avoidance skill training, and further note a need for bridge organization training. Each of these areas is broad, covering a wide variety of skills. The design of a cost effective simulator, together with the training program, necessitates the definition of a precisely defined set of objectives to be achieved via training on the simulator.

The characteristics of the world's ship bridge simulators vary widely (e.g., nocturnal scene only versus night and day; color scene versus black and white scene;  $\pm 60$ -degree field of view versus  $\pm 120$ -degrees). The first international meeting of maritime simulator designers, operators, and users (MARSIM '78) highlighted the substantial differences among today's ship bridge simulators. These differences also pertain to the training objectives and methodologies used by the different simulators (e.g., fundamental shiphandling training, emergency shiphandling training, collision avoidance training, and bridge team/organizational training). Of interest were the reports by virtually every simulator operator of the industry-wide acceptance its particular configuration has received, primarily based on the subjective evaluations of the users. These findings are important in that they demonstrate acceptance for training on bridge simulators. Furthermore, they attest to the apparently acceptable level of face validity for all simulators. The relative effectiveness of the different simulators, however, must differ as a function of their design characteristics. The costs of the simulators in operation today span a range of twenty to one. Hence, the relative cost effectiveness of each simulator is likely to vary considerably for the training of particular skills. In essence, little objective information is currently available with which to select simulator and training program characteristics to be used for the development and/or improvement of mariner skills.

Objective information needs to be developed pertaining to (a) the specific objectives to be achieved via simulator-based training, (b) the relative effectiveness of alternative simulator characteristics and training program characteristics in achieving the stated objectives, and (c) the transferability and retention of skills learned or improved on the simulator to actual performance at sea. This information would be instrumental in enabling cost effectiveness tradeoffs to be made by designers, purchasers, and users of maritime simulators. Training represents one aspect of the solution to the need for improved safety. The relative cost effectiveness of different training approaches (e.g., on-the-job training, classroom-only training, and simulator-based training), at-sea experience, and operational system design require delineation.

#### 1.4 LONG-TERM PROJECT GOALS

The potential advantages to be derived from simulator-based training center around improved mariner skill, and safety and cost effectiveness in acquiring that skill on a simulator. Likewise, the dangers of simulator-based training center around poor cost effectiveness as a result of improper design and use. Little objective information is available today to assist in decisions regarding the design and use of simulation in the mariner training and licensing process. Legislative action has been passed by the United States specifically addressing mariner training and licensing, and the use of simulators. The Port and Tanker Safety Act of 1978 (Public Law 95-474 - Oct. 17, 1978, 92 Stat. 1471) requires that standards be established for:

"instruction in vessel and cargo handling and vessel navigation under normal operating conditions in coastal and confined waters and on the high seas:

instruction in vessel and cargo handling and vessel navigation in emergency situations and under accidental or potential accident conditions:

license qualifications by specific type and size of vessels:

qualification for licenses by use of simulators for the practice or demonstration of marine-oriented skills:

periodic retraining and special training for upgrading positions, changing vessel type or size, or assuming new responsibilities: and

determination of licenses and certificates, conditions of licensing or certification and period of licensing or certification by reference to experience, amount of training completed, and regular performance testing."

Objective information needs to be generated and compiled regarding the strengths and weaknesses pertaining to the design and use of simulation in the maritime industry. This information should pertain to characteristics of the simulator and the associated training program, the use of the simulator in training, and the cost effectiveness/feasibility of simulator-based training.

The long-term goal of the project is to develop an information base from which positions, decisions, and actions may be formulated to raise the licensing and qualification standards of mariners. More specifically, this project will thoroughly investigate the potential role of simulators, and develop the information base to document subsequent recommendations, in support of improving the training and licensing of mariners. Simulators, both part-and whole-task, are expected to be an important aid in the achievement of higher qualification standards. This goal is in direct response to the Port and Tanker Safety Act of 1978 (which was in proposal form when the project began). It is also in response to the presidential message to Congress on March 17, 1977 which stated:

"I am instructing the Secretary of Transportation to take immediate steps to raise the licensing and qualification standards for American crews.

"The international requirements for crew qualifications, which are far from strict, will be dealt with by a major international conference we will participate in next year. I am instructing the Secretary of Transportation to identify additional requirements which should be discussed, and if not included, may be imposed by the United States after 1978 on the crews of all ships calling at American ports." (Carter, 1977)

The long-term goals draw partial international support from the IMCO - International Conference on Training and Certification of Seafarers, 1978 (IMCO, 1978). Resolution 17 (STW/CONF/20, page 116) adopted by the conference recommends that masters and chief mates, before assuming their duties on "large ships or ships having unusual handling and maneuvering characteristics significantly different from those in which they have recently served", have sufficient experience on that or a similar ship, or "have attended an approved ship handling simulator course on an installation capable of simulating the maneuvering characteristics of such a ship". This resolution calls for transition training, recommending either appropriate experience or simulator-based training. (Please note that a participant of the IMCO conference has indicated that this resolution was intended to make a shiphandling training capability available to third-world nations not having

appropriate ships for providing the necessary experience.)

The products resulting from the long-term effort will pertain to areas of mariner training appropriate for the use of simulators. This may include deck and engineering officers; upgrading, transition, and refresher training; basic and advanced training. Several long-term products are envisioned at the present time. These include:

- a. The delineation of the potential role of simulators in mariner training and licensing. This will include a description of the feasibility and effectiveness of simulator use in the various areas; it will also include detailed investigation of simulator characteristics and their tradeoffs.
- b. Training Program Guidelines. A set of guidelines will be developed for each area amenable to the use of simulator training. These guidelines will provide the framework within which the simulator-based training can, and should, be accomplished. The guidelines would address the strengths and weaknesses of the training in each area, alternative training strategies, training objectives, and performance measures and standards.
- c. Training Program Acceptance Criteria. A methodology will be developed for establishing appropriate training system evaluation criteria, and using those criteria to evaluate the effectiveness of simulator-based training programs.

This project is extremely broad in scope, and is expected to span several phases. This document reports on the initial phase of the investigation.

## 1.5 PHASE 1 GOALS

The initial phase of the project has been directed toward the development of an effective investigative methodology, development of a comprehensive data base pertaining to mariner behavior and training system design, and the identification of knowledge gaps for the direction of subsequent empirical research. The specific Phase 1 objectives were to:

- a. Compile task analysis data to identify the tasks performed by a deck officer.
- b. Identify the skills and knowledge required of a qualified merchant mariner
- c. Identify the factors that influence the level of skill and knowledge required
- d. Delineate the potential uses of simulators to develop and demonstrate the skills
- e. Identify the factors that affect the feasibility of using simulators to improve and/or demonstrate mariner skills, relative to other means of skill acquisition
- f. Delineate the issues that require further investigation.

These Phase 1 objectives, in essence, attempt to identify the issues relevant to the use of a simulator for training. The investigation centers on the research literature to compile that which is known about simulators and training. Furthermore, Phase I seeks to identify those issues that require additional research or investigation.

Each of these objectives has been met during Phase 1. Their accomplishment is discussed in detail in the Appendices, and summarized in the following sections of this report. The findings address each of the objectives.

## CHAPTER 2

### APPROACH

The methodology used during Phase 1, and to be used during subsequent phases, was developed specifically for this investigation. The unique factors concerning the use of simulation in the mariner training and licensing process necessitated the development of a methodology drawn from similar experiences in other fields, but tailored to the specific needs of this field.

#### 2.1 PROJECT TEAM

An issue of importance was the composition of the project team. The diverse nature of the problem area necessitated a multidisciplinary team to ensure adequate treatment of the differing fundamental elements of the problem. The three fundamental elements were identified as: (a) training technology, (b) simulation technology, and (c) maritime operations, training, and licensing. A mix of personnel with expertise in each of these was required to achieve an applicable product, due to the highly specialized nature of each element and its potential impact on the end product.

The assembled multidisciplinary team was composed of the investigation team and the working group. The investigation team included the government and contractor personnel directly involved with the technical conduct of the investigation. All contractor personnel involved in this project have had previous experience working in the marine field, in a variety of capacities including that of research scientist/engineer, unlicensed seaman, and/or licensed officer. The primary function on the investigation team was training psychology since this represents the major concern of the investigation. The team was headed by a psychologist/engineer experienced in the research, development, and application of training/simulator systems. Several other individuals on the investigation team also had formal backgrounds in training and/or psychology. Of these, one has served as an able-bodied seaman, and one has served as the commanding officer of a naval vessel. This segment of the team formulated the technical approach and performed most of the analyses. They were assisted by the simulation and maritime operations specialists, as noted below. Several of the training/psychology specialists also served the project in more than one capacity, and are included in the simulation technology and maritime operations segments of the team noted below.

The investigation of simulation technology is a major function of the project. Several individuals included in the team have had extensive experience in the research, development, and application of simulators, including maritime simulators. Four team members had expertise in training/psychology and simulation; two team members had sea-going experience in addition to simulation expertise. This segment of the team performed the analyses pertaining to simulator characteristics.

The third major element of the investigation team was maritime operations. Individuals with a variety of maritime-related backgrounds performed in this capacity. Six individuals held deck licenses, including four masters; three individuals held engineer's licenses, including two chief engineers; two of these individuals also held pilot licenses, and one was dual licensed as a deck officer and engineer. The experience of these individuals spanned a variety of vessel types and sizes, including LNG carriers. The functions of this segment of the team spanned all the project tasks, usually in the capacity of a consultant. Their functions dealt primarily with 1) ensuring operational maritime

validity in the concepts developed and conclusions reached, 2) identifying relevant operational maritime concerns and problems to be considered during the project, 3) providing a source of maritime expertise to address operational aspects of the project, and 4) providing review of, and modification to, the products, conclusions, and recommendations of the project. The contribution of licensed officers varied considerably, from full-time developmental efforts (e.g., behavioral data base) to the review of prepared material.

The government personnel involved with the project represented applied research and development expertise, and operational maritime and U.S. Coast Guard expertise. Their function was two-fold: (1) to direct the thrust of the project in response to identified needs, and (2) to review the developed material.

The working group, which interfaced with the investigation team, assisted by representing the ultimate user and recommending directions in which the project should proceed. The working group was composed of representatives of ship operators, labor unions, academies, and training facilities. These individuals have had extensive experience spanning the various aspects of the maritime field. Their function was to interface with the contractor, review the approach and findings during Phase 1, and suggest appropriate modifications.

The project team thus represented a wide range of interests and expertise concerning the many facets of the project. Three joint quarterly meetings were held during which the working group made a variety of suggestions concerning the direction of the project. Many of these suggestions resulted in modifications during Phase 1. The major suggestions included:

- a. Initial de-emphasis of the investigation of licensing issues, with concentration placed primarily on the training value of simulation. The investigation of licensing issues was concluded, with further investigation postponed to later phases, subsequent to the more thorough investigation of training issues. This was seen as consistent with the U.S. Coast Guard preference for approaching simulator licensing, if at all, through the approval of simulator training courses rather than through training independent simulator tests. A similar concept appears to be implied by Resolution 17 of the IMCO Convention on Standards of Training and Watchkeeping, July 1978.
- b. Modification of the initial objectives which were directed toward a specific subset of mariner training (i.e., transition training between a 30,000 dwt tanker and a 250,000 dwt tanker; master to master with pilot endorsement; and a vessel with high horsepower/weight and low block coefficient to a vessel with low horsepower/weight and high block coefficient) to investigating a more general subset of mariner (i.e., shiphandling skills of masters of various classes of vessels). The initial Phase 1 objectives were modified as suggested by the working group. Masters in general were investigated without regard to pilot endorsement or a specific area of training. Additionally, the investigation was limited to restricted waters and skills that could be attainable via simulator-based training.
- c. Modification of the developed set of specific functional objectives. These have been modified as suggested.

A variety of other modifications were suggested, many of which have been followed. The intent of this working group was to provide a fundamental input to the project from the ultimate users; this was considered an essential part of the developmental process.



## 2.2 SYSTEMS APPROACH TO TRAINING

The approach followed during Phase 1, and that to be followed in the later phases of the investigation, was adapted from an approach developed and used extensively by the United States Air Force and Navy. This methodology, known as the systems approach to training, was developed for the design and evaluation of simulator-based training systems. It is the approach generally accepted and followed by training/simulation specialists for the development of military and civilian simulator-based training systems (e.g., Chenzoff and Folley, 1965; Cream, Eggemeier, and Klein, 1978; Gagne, 1966; Jeantheau, 1970; Smode, Gruber, and Ely, 1963). The methodology consists of a series of sequential steps to identify the specific objectives to be attained by the training system, followed by cost effectiveness evaluation and tradeoff analyses among the variety of alternative characteristics of the different system elements. This methodology seeks to create a structure within which the somewhat subjective information can be compiled. Design decisions can then be made on the basis of objective evaluation of the available information.

The training system concept is an essential part of this process. Earlier experience in the design of simulator-based training devices has shown that it is a mistake to design a simulator independently of the other training system elements. Rather, to achieve a cost effective design, all the elements relevant to the training process must be designed as a systematic whole (Blaiwes, Puig, and Regan, 1973). Training system elements are typically viewed as including (a) specific functional objectives (i.e., behavioral training objectives) -- the specific skills and abilities to be achieved during training, (b) simulator part-task and/or whole-task hardware and software; (c) the training program, including structure (e.g., framework of courses), the training process strategy (e.g., training methodologies, mix of classroom and simulator training, exercise design, and timing and content of feedback), and training support material (e.g., visual aids and performance measures); and (d) training personnel. As several investigators have pointed out, substantial differences in the effectiveness of training on a particular device may result from differences in any of these elements (e.g., Meister, Sullivan, Thompson, and Finley, 1971). Furthermore, the most cost effective system design results from the simultaneous design of these elements.

The actual methodology developed and used during Phase 1 is an adaptation of the systems approach to training. Each of the above elements has been addressed in one or more tasks during the effort. The goals, in addition to methodology development, have been to compile the currently available information pertaining to each element of the training system, and to identify the knowledge gaps. The methodology used is illustrated in FIGURE 1. The seven tasks represent the initial approach taken in Phase 1, which has been modified throughout the effort. The methodology used in each of the task areas is presented in detail in the appropriate appendices. The findings resulting from each task are discussed in detail in the appendices, and summarized in Section 3.

## 2.3 TASK AREAS

### 2.3.1 Develop Behavioral Data Base

A behavioral data base was assembled to define the training objectives of the training system in the form of specific functional objectives (SFOs). The SFOs represent, in detail, the goals of the training system, and goals for which the system elements would be designed. This developmental effort concentrated on the master's position, pertaining to

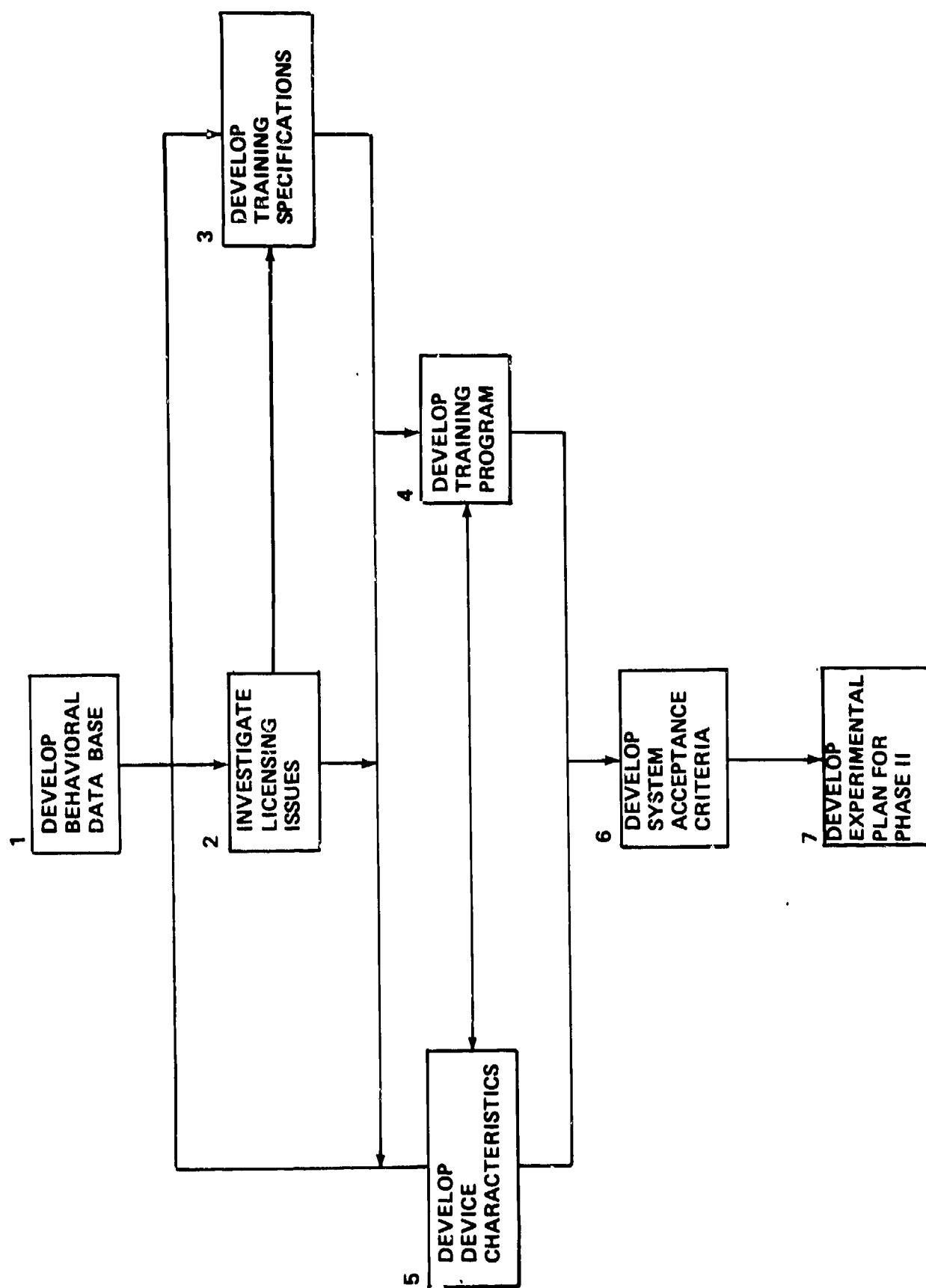


Figure 1. Training and Licensing Project Work Plan

maneuvering of the vessel in restricted waters, for several different classes of vessels. Several sequential subtasks were conducted to develop the SFOs. First the master's tasks related to shiphandling were identified. A task analysis was not conducted; rather, the at-sea task analyses conducted during several previously performed independent studies were compiled into a comprehensive set of tasks. This set of tasks provides an objective description of the master's activities.

Secondly, the skills and knowledge underlying each of the master's tasks were delineated. The skills and knowledge are typically common to several different tasks. The development and improvement of the master's skills and knowledge is the purpose of the training process. The skills and knowledge were derived from an analysis of the master's tasks by a training analyst and several maritime consultants.

The third subtask, trainee input characteristics, identified skills, knowledge, and level of performance that the master would be likely to possess prior to entering the training program. The input characteristics were derived by a training analyst and maritime consultant through:

- a. Review of USCG tests for masters and chief mates, and
- b. Discussions with practicing mariners

A set of characteristics was developed for a hypothetical port, Port XYZ, as the fourth subtask. Port XYZ represents a compendium of the port characteristics likely to be found around the world. The characteristics were compiled by experienced mariners based on available documentation and experience. The Port XYZ characteristics and the lists of required skills and knowledge, along with casualty information, represented an important data source for the development of SFOs.

The final subtask involved the development of the specific functional objectives. They explicitly detail the skills to be developed and/or improved via the training program. They furthermore specify the conditions under which the SFOs should be achieved. The SFOs were developed from the skill and knowledge requirements, input characteristics, Port XYZ characteristics, and a brief analysis of casualty information. Practicing mariners reviewed the SFOs, which were modified in accordance with their recommendations.

The specific functional objectives represent the major product of this task. They were reviewed by the working group and modified as a result.

### 2.3.2 Licensing Issues

The purpose of this task was to review current licensing practices and identify issues pertinent to the use of simulation. Initially, emphasis was to have been placed on the concept of transition between vessels with substantially different handling characteristics, and on a master obtaining a pilot endorsement. As a result of recommendations of the working group, this task has been postponed until the issues related to training have been more thoroughly investigated. Work was continued on portions of this task until a logical stopping point was reached. This work is reported in the appendices.

The subtasks that were planned, but not completed, include the: (a) identification of areas of deck officer training/licensing amenable to the use of a simulator, (b) identification

and investigation of issues relevant to each area of training/licensing, (c) development of licensing categories for transition training and, (d) development of a structure within which training/licensing could be achieved.

Many of the subtasks were begun, and in some cases concluded prior to the changes of emphasis. The airline/FAA training and licensing process was reviewed, identifying practices, similarities, and differences with the maritime industry. The nuclear power generation/NRC training and licensing process was also reviewed. Both of these industries are similar to the maritime industry in that standards are set and licenses issued by a government agency. Both the airlines and power generation industries rely on simulation as a part of the training and licensing process. Information was collected regarding their training and licensing structure, and their design and use of simulators. The information was collected from the literature, observation of training at their facilities, and discussions with appropriate people.

The IMCO positions on training and licensing of mariners have been reviewed and factored into this task as well as other tasks. This review was based on investigation of IMCO documentation and discussions with delegates and other individuals active in the IMCO proceedings.

Current deck officer licensing practices in the United States and other countries were reviewed and data compiled. Issues relating to licensing categories, including the demand for licenses, criteria for license categories, and licensing evaluation practices were identified and discussed and recommendations made.

The investigation of licensing issues was necessarily incomplete due to its premature conclusion during Phase 1. As a result, the findings stemming from this task have not been completely factored into the other tasks, as originally anticipated. The findings are independently discussed in Appendix F.

### 2.3.3 Training Specifications

The training specifications represent a fundamental input to the design of the training system, as they bridge the gap between the SFOs and the system's developed components (i.e., simulator and curriculum). The training specifications delineated those factors that affect the attainment and/or improvement of shiphandling skill. These factors include:

- a. Compilation of an information base pertaining to training technology state of the art, including Army, Navy, and Air Force training methodologies, and maritime training practices.
- b. Specified characteristics of information required for the performance of each skill.
- c. Training methodological factors (e.g., feedback information characteristics) appropriate for each skill.
- d. Development of performance measures to evaluate shiphandling skills; these will be used for diagnostic placement and analysis of SFO achievement.

This task generated a training technology information base that was used in the development of the training program guidelines and the evaluation of alternative simulator characteristics. This task specifies the optimum characteristics for each SFO.

The training program and simulator tasks, both of which are discussed below, integrate the individual SFO specifications on the basis of cost effectiveness tradeoffs to achieve the final system design. A training specialist, simulation specialist, and several maritime consultants conducted the task. It was based on an extensive review of the general training literature, review of current maritime training practices, review of maritime research, knowledge of maritime operations, and knowledge of training and simulation technology.

#### 2.3.4 Training Program

The training program, as noted earlier, is a fundamental element of the training system. It must be developed in parallel with the simulator characteristics to ensure a cost effective training system. This task accomplished the initial step in the development of the training program. It developed a detailed set of guidelines which represent the framework for the complete training program development. The guidelines specify, in detail, the topics to be covered during training, their order, the context in which they should be achieved (e.g., simulator or classroom), and the training methodologies. The guidelines represent the SFOs transformed into a curriculum outline that considers the practical mechanics of the training system.

The training program guidelines were developed to achieve the SFOs, based on the training specifications and other information. The four major subtasks were to:

- a. Review the current maritime training practices at the master's level
- b. Develop a training program structure under which simulator-based training might be achieved
- c. Develop detailed training guidelines (the content within the proposed structure)
- d. Develop a diagnostic analysis scenario for evaluating the strengths and weaknesses of masters/trainees. This diagnostic tool would be used to tailor the training program to specific individual or group needs.

The guidelines were developed by training specialists and maritime consultants, taking into consideration (a) the SFOs, (b) likely simulator characteristics, (c) at-sea operations, and (d) practical mariner training factors. The resultant product recommends a proposed cost effective structure for the implementation of shiphandling training.

#### 2.3.5 Simulator Characteristics

The objective of this task was to compile cost effectiveness information pertaining to the alternative characteristics of shiphandling simulators. These characteristics may pertain to part- and/or whole-task simulators. The information generated by this task, and the methodology developed, would be instrumental in the design/purchase of a shiphandling simulator. The specific subtasks were to:

- a. Compile information pertaining to simulator technology in general (e.g., Navy and Air Force)
- b. Investigate and summarize the current state of the art in maritime simulation technology

- c. Identify subsystems of the shiphandling simulator concept
- d. Identify the fundamental characteristics of each subsystem
- e. Identify alternative means of achieving the subsystem characteristics within the simulation technology state of the art
- f. Identify the capabilities and limitations associated with each alternative characteristic based on available information and mariner experience
- g. Estimate the relative effectiveness of each alternative characteristic as it pertains to each SFO
- h. Identify the relative costs associated with alternative characteristics

The final two subtasks provide effectiveness and cost information regarding the alternative characteristics, enabling the development of cost effectiveness ratios. These subtasks developed and denote the procedure to be followed in designing the simulator, and also provide a comprehensive maritime simulation information base. This task required the close integration of expertise in maritime operations, maritime training, training technology, and simulation technology. This task represents the completion of the training system design.

#### 2.3.6 Training System Acceptance Criteria

The training systems in use today, and those that will be developed, are likely to have differing levels of effectiveness in achieving SFOs. A major consideration is the effectiveness of simulator-based training programs relative to other methods of acquiring the necessary levels of shiphandling skill. This issue is of particular importance to regulatory bodies (i.e., the USCG) whose function may be to allocate credit in the licensing process for having successfully completed a training program. The problem thus faced concerns the amount of credit to be given for completing a particular training program. A methodology is necessary that would enable (a) the development of appropriate evaluation criteria for shiphandling skill in a particular operational problem area (e.g., pilotage into a specific port), and (b) the development of a methodology by which the effectiveness of a given training program could be evaluated relative to the criteria, and from which an appropriate amount of credit would be established for individuals completing the training program. The criteria and the amount of credit would be responsive to all the relevant factors involved (e.g., local knowledge, shiphandling skill, and skill retention over time after training).

This task is directly related to the use of simulator-based training to impact the licensing process. Since it was scheduled to begin late in Phase 1, and since the licensing issues were subsequently de-emphasized, this task was not conducted. The training system acceptance criteria will be addressed in a later phase, in which they will address those specific functional objectives that are most suitable for simulator training.

#### 2.3.7 Experimental Plan

A major product of Phase 1 is the identification of knowledge gaps in the design of a maritime simulator-based training system. The identification of these knowledge gaps, leading to the specification of research issues, was developed under this task. The research issues were based on analysis of the information available pertaining to each of

the Phase 1 tasks. The knowledge gaps represent the need for empirical research. Experience in the maritime simulation/training field has indicated that there is a startling absence of objective information pertaining to the effectiveness of simulator-based training, the effectiveness of alternative training system characteristics, and their transferability to the at-sea environment. Appropriate objective information needs to be collected to improve the cost/effectiveness of training system design.

The Phase 2 effort will collect empirical information regarding high priority research issues. The experimental plan for Phase 2 was developed under this task. It provides the detailed structure for the conduct of Phase 2. It was developed on the basis of information generated in earlier tasks.

The methodology presented herein represents both the approach taken during Phase 1, and a major product of Phase 1, i.e., the development of a feasible methodology for the investigation and design of a maritime simulator-based training system.

## CHAPTER 3

### FINDINGS

The findings from Phase 1 are contained in several parts of this report. Those pertaining to development of the investigative methodology are discussed in the Section 2, with supporting information in the appendices. Those findings that pertain directly to the Phase 1 objectives (see section 1.6) are discussed in section 3.2, while other important findings are summarized in section 3.1. The in-depth presentation and discussion of findings is contained in the appendices, the organization of which generally follows that of the Phase 1 tasks.

The general goals of Phase 1 were three-fold. The first goal was to investigate the feasibility of simulation in the mariner training and licensing process. This was accomplished in the form of the developed methodology, as presented and discussed in Section 2. The second goal was to develop an information base pertaining to the maritime training problem. This was achieved in the form of a comprehensive behavioral data base of the master's shiphandling tasks, skills, and SFOs; an information base pertaining to the training technology state of the art; a summary of the ship bridge simulators and training programs; delineation of ship bridges similar characteristics, capabilities, limitations, and effectiveness; shiphandling training program guidelines; and potential performance measures. The information and observations are discussed in detail in the appendices, and are summarized below. The third goal was to identify gaps in the available knowledge pertaining to the design and use of a simulator-based mariner training system. This has been achieved in the form of research issues, which are discussed later in this section.

#### 3.1 SUMMARY OF FINDINGS

As could be expected from the broad nature of the maritime training problem, a wide variety of findings has resulted from the Phase 1 effort. Many of these findings pertain to compiled information and are contained in the various appendices. Much of the information represents interim products necessary to achieve the Phase 1 objectives. The findings not discussed later are summarized below.

##### 3.1.1 Training Technology Information Base

A comprehensive information base was developed pertaining to the state of the art in training technology, in particular that impacting maritime simulator-based training. This information base pertains to the two most important elements of the training system, the simulator and the training program. Among the items contained in the information base are:

- a. A detailed comparison of the characteristics of the major ship-bridge simulators worldwide. Included are the simulators at the College of Nautical Studies, Southampton, U.K.; Computer Aided Operations Research Facility, New York; Hochschule fur Nautik, Bremen; Ishikawajima-Harima Heavy Industries Co. Ltd., Tokyo; Marine Safety International, New York; Netherlands Ship Model Basin, Wageningen; Swedish State Shipbuilding Experimental Tank, Gothenburg; TNO--Institute for Mechanical Construction, Delft; TNO--Institute for Perception, Soesterberg; and others. (See Appendix E, Exhibit E-1.)



- b. A comparison of the curricula and training methodologies used at the different simulator facilities. This information is incomplete. Some of the training material is considered proprietary and, therefore, was not available. (See Appendix D, Exhibit D-1.)
- c. A review and discussion of the current state of the art in training technology (Appendix C). This includes:
  - 1. Simulation technology (fidelity issues, design and use considerations, part-task versus whole-task, etc)
  - 2. Training methodologies (positive guidance, self-evaluation, individual training versus team training, etc)
  - 3. The training of skills and abilities
  - 4. Training curriculum design considerations
  - 5. The necessity of training effectiveness evaluation on the simulator followed by evaluation of the transfer of training to the at-sea environment.
- d. Investigation of commercial applications of simulation for training. This includes the discussion of the use of simulator-based training programs in commercial aviation and in nuclear power generation industries. (See Appendix F.)
- e. Identification of the information characteristics deemed necessary to achieve each SFO (Appendix C). These information characteristics would have to be provided by the training system, i.e., via a combination of simulation and training curricula.
- f. Identification of the training methodology characteristics deemed appropriate for each SFO (Appendix C). The training program, including exercises and feedback techniques, should be developed in accordance with these methodological considerations to achieve an effective training process.

### 3.1.2 Deck Officer Behavioral Data Base

Several relevant deck officer task analyses, representing a massive amount of data, were located in the available literature. The analyses were conducted at-sea during independent investigations over the past 10 years. They covered a range of vessels (e.g., containership, dry bulk carrier, and tanker) and personnel (i.e., all deck officer and pilot positions, although concentrating on the master). The areas of operation included both the United States and Europe, but were primarily in restricted waters, e.g., harbors, English channel, Puget Sound, and Gulf of Mexico. The spectrum of environmental conditions was covered. The integration of the tasks into a cohesive set revealed that each task analysis emphasized different factors, and thus had more finite task descriptions in the task area of interest to that particular study (e.g., collision avoidance or communications). The integration of the different analyses is therefore representative of the broad scope of deck officer tasks at a detailed level. The final set consists of 290 tasks, of which 178 may be performed by the master (Appendix A, Exhibits A-1 and A-2). These tasks span the areas of ship control, communications, navigation, collision avoidance, signaling, management and crew coordination, docking, mooring, and anchoring. For obvious reasons few tasks were observed in emergency shiphandling. This integrated set of tasks forms the foundation on which the remaining parts of the behavioral data base were developed, leading to the SFOs.

The skills and knowledge of the master were determined directly from the tasks, as well as other available information. This effort resulted in the identification of 62 skills and 98 knowledge items (Appendix A, Exhibits A-5 and A-6). They covered a broad range, yielding the following groupings:

- Navigation
- Communication
- Environmental elements
- Radar/collision avoidance
- Maneuvering
- Docking, mooring, anchoring
- Emergencies

A set of input characteristics was developed for a master of a tanker in the 30,000 dwt class, representing those skills and knowledge he is likely to possess prior to entering the training program. This effort showed that the skills of a master on different vessels are likely to be similar. The masters are expected to differ, however, with regard to their performance level in particular skills. However, the level of performance of that skill is likely to vary according to the vessel's particular characteristics.

The initial sets of task analyses in the literature represented a massive amount of data pertaining to merchant vessel operations. This information was reduced via the integrated set of tasks, the skills and knowledge requirements, and the identification of input characteristics to a workable-sized group of specific functional objectives (SFOs). The SFOs represent the behavior to be achieved by the training system. The SFOs were developed, as noted above, and then modified several times (i.e., in accordance with the modified Phase 1 objectives, Port XYZ characteristics, emergency and difficult shiphhandling situations, and review by the working group and other experienced mariners). The final group of SFOs represents the training objectives to be achieved by a shiphhandling simulator-based training system.

## 3.2 RESULTS AND DISCUSSION

### 3.2.1 Shiphhandling Training System

The approach followed during Phase 1, as presented in the previous section, outlines a maritime shiphhandling training system. This approach identifies the needs for training based on observed at-sea tasks and developed specifications, independent of the design of current simulators. The current maritime simulators are considered in terms of 1) the capabilities and limitations of alternative simulator characteristics, and 2) effectiveness estimates for each alternative simulator characteristic regarding each SFO.

Specific Functional Objectives. Deck officers perform a wide variety of tasks, many of which are unrelated to bridge operations or shiphhandling (e.g., administrative and managerial tasks and cargo handling). Additionally, other shiphhandling tasks are unlikely to be performed by the deck officer without the assistance of a pilot (e.g., docking). The following set of 74 shiphhandling SFOs represent those deck officer skills to be achieved for shiphhandling in restricted waters.

Each SFO comprises two segments:

- a. Conditions which describe the circumstances under which behavior should be performed; and
- b. Behavior which is the specific skill and/or knowledge to be attained by the master as a result of training and/or experience. (See Appendix A, A-5 for skill requirements and A-6 for knowledge requirements).

Fourteen conditions were established to incorporate the major situations which may exist while maneuvering large vessels in restricted waters. These conditions apply to each of the functional objectives specified below unless otherwise stated.

- a. Varying degrees of visibility:
  - 1. Visibility limited to own ship's bow
  - 2. 0-1 mile
  - 3. 2-5 miles
  - 4. Unlimited
- b. Specific geographical constraints of varying complexity:
  - 1. Channel width
    - (a) Minimum of 700 ft
    - (b) 1200 ft
    - (c) 1500 ft
  - 2. Varying channel depths; minimum of two (2) feet below the keel of the ship
  - 3. Geographical obstacles, both visible and submerged.
- c. Ship Traffic:
  - 1. None
  - 2. Light (1-5 contacts)
  - 3. Medium (6-10 contacts)
  - 4. Heavy (over 10)
- d. Varying environmental conditions:
  - 1. Wind
    - (a) 0-10 knots
    - (b) 10-25 knots
    - (c) 25-50 knots
  - 2. Current
    - (a) 0-3 knots
    - (b) 3-5 knots
  - 3. Tide
    - (a) 0-5 ft
    - (b) 5-10 ft
    - (c) 10-15 ft
    - (d) 15-20 ft
  - 4. Varying conditions of wind, current, and tide
- e. Various own ship speeds:

1. 0-5 knots
  2. 5-10 knots
  3. 10-15 knots
  4. 15-20 knots
- f. Various loading conditions:
1. Light
  2. Fully loaded
  3. Ballasted
- g. Visual details:
1. Day
  2. Night
  3. Fog
- h. Sea states:
1. 0-3
  2. 4-5
  3. Over 5
- i. Weather:
1. Rain
  2. Snow
  3. Sleet
  4. Clear
- j. Different ship types (i.e., VLCC, containership, LNG) sizes, characteristics (e.g., turning circles), and tonnages of ships
- k. VTS information:
1. Available
  2. Not available
- l. Vessel proceeding:
1. Inbound
  2. Outbound
- m. Navigation aids on board will vary
- n. Changeability of conditions:
1. Conditions a through m should be varied during training exercises.

The SFOs are presented in detail below, grouped into five categories that span the major areas required for the training of shiphandling skills. These categories are:

- I. Fundamental Ship Handling: Objectives which require the understanding of how a vessel will respond based on variables such as the vessel's configuration, its mass, its power (or lack of it), its reaction to currents, winds, interactions, speeds, response times, magnitudes and distances. These variables, though constantly changing must be resolved into definite rudder or engine orders.

- II. Integrated Ship Handling: Objectives which address the skills required to successfully handle the vessel in all types of situations (e.g., conning through a channel, docking, mooring, anchoring) and under various conditions, while taking into account the combination of fundamental variables which will affect the vessel's response.
- III. Emergencies: Objectives which require the understanding of vessel characteristics to allow for the proper shiphandling decisions to be made and, if possible, perform corrective ship control actions to successfully ensure vessel and crew safety when personnel ship control errors or power, rudder, equipment or electrical failures occur.
- IV. Team Coordination/Communication: Objectives which require each team member to perform parallel and serial functions in coordination with the other team members in a timely manner and within a framework of set procedures which are situation dependent.
- V. Bridge Procedures: Objectives which require the bridge team to organize and carry out the duties and pattern of communications required to properly execute the port entry/exit passage plans, especially when the unexpected arises.

## I. Fundamental Ship Handling

### A. Ship-Environmental Effects

Maneuver the vessel, holding course and heading under both steady state and varying environmental conditions:

- 1. Wind speeds of 0-50 knots (any direction)
- 2. Current speeds of 0-5 knots (any direction)
- 3. Sea state of 0-9
- 4. Any combination of 1 through 3 above.

### B. Ship Characteristics

- 1. Understand and handle properly the following factors involved in ship maneuvers:
  - a. Drift angle
  - b. Advance and transfer
  - c. Tactical diameter
  - d. Diameter of a steady turning circle
  - e. Pivoting point
  - f. Loss of speed in turn
  - g. Angle of heel in turning
  - h. Displacement
- 2. Understand and handle properly the following elements in ship control actions:
  - a. Rudder response (starboard and port -  $5^{\circ}$ ,  $10^{\circ}$ ,  $15^{\circ}$ ,  $20^{\circ}$ ,  $25^{\circ}$ ,  $30^{\circ}$ )
  - b. Acceleration, deceleration (use of tables)
  - c. Heading change rate and its time dependency
  - d. Effect of rpm change on turning characteristics (i.e., increase or decrease in rpm) such as kick effect
  - e. Effect of draft
  - f. Effect of freeboard

3. Understand and apply the following to ship maneuvering situations:
  - a. Maneuvering as a function of ship speed
  - b. RPM change time delay, including forward to reverse
  - c. RPM change rate over time
4. Understand and apply the effect of the following on stopping distance, time, and position:
  - a. Effect of draft
  - b. Effect of freeboard
  - c. Effect of block coefficient
  - d. RPM factors (e.g., engine time to reverse)
  - e. Rudder factors (e.g., deceleration in turn)
  - f. Deceleration tables
5. Stop the vessel, predicting its time-dependent path, considering various displacements, speeds, astern rpm, and engine time to reverse, using each of the following techniques:
  - a. Rudder cycling
  - b. Coasting stop
  - c. Full engine reverse
  - d. J stopping maneuver
  - e. Crash stop
  - f. Other stopping devices such as variable pitch propeller, twin screw, and rotatable propeller

#### C. Hydrodynamic Effects

1. Compensate for or take advantage of the effect of suction between ships as well as between own ship's quarter and the shallower water at the edge of the fairway when:
  - a. Maneuvering around docks
  - b. Maneuvering in confined waters
  - c. Meeting or passing another vessel in a confined channel
2. Compensate for or take advantage of bank effects when maneuvering through the channel.

#### D. Maneuver Techniques

1. Execute a zig-zag (Kempf) maneuver, projecting own ship's track:
  - a. At a speed of 15 knots in the open sea, prior to the maneuver
  - b. Using no greater than a 20° rudder angle
2. Execute a spiral maneuver, projecting own ship's track:
  - c. At a speed of 15 knots in the open sea, prior to the maneuver
  - d. Begin by putting over a 15° starboard rudder
3. Execute a Williamson turn to pick up a man overboard in reduced visibility.
4. Maneuver the vessel through the channel under high wind conditions, using the kick effect to assist in maintaining own ship's position within the channel.
5. Plan and carry out when to initiate a turn by determining the amount of rudder, the use of rpm, and other operations (e.g., kick effect) along with the correct timing for implementation.

## E. Rules-of-the-Road

1. Detect and interpret ship traffic for required collision avoidance actions when own ship is the stand-on vessel and the following situations exist:
  - a. Head-on
  - b. Overtaking
  - c. Crossing
2. Detect and interpret ship traffic for required collision avoidance actions when own ship is the give-way vessel and the following situation exists:
  - a. Head-on
  - b. Overtaking
  - c. Crossing
3. Sound the appropriate whistle signals in compliance with the regulations specified for the Rules of the Road when:
  - a. Maneuvering and using warning signals
  - b. Using sound signals in restricted visibility
  - c. Sounding distress signals

## II. Integrated Shiphandling

### A. Port Entry

1. Develop port entry, channel navigation, and docking plan with alternatives. Execute the plan with the necessary alterations.

Navigate the vessel through the waterway plotting own ship's position with data obtained from the following using other methods as necessary:

2. Decca
3. Loran
4. RDF
5. Visual fixes
6. Radar
7. Navigate through the waterway, operating a depth finder to determine water depth and assist in fixing own ship's position
8. Navigate through the waterway, operating a radar unit to aid in the detection of navigational hazards and aids
9. Maneuver the vessel through the waterway, communicating via ship-to-ship, using the proper VHF frequencies, exhibiting proper terminology and procedures to avoid collisions
10. Communicate with the pilot boat or with tugs for planning purposes when entering the port, exhibiting proper terminology and procedures
11. Communicate via ship-to-shore to determine docking location and have docking preparation initiated
12. Send/receive communication from the pilot as to "what side of the ladder" and weather at the station, using the appropriate terminology and procedures
13. Maneuver the vessel to come to slow and decide whether to turn to right or left for lee to pick up/drop off a pilot
14. Approach the channel, entering the appropriate traffic separation schemes when varying traffic density and various types of ships are present.

**B. Restricted Waterway/Channel Navigation and Shiphandling**

Maneuver the vessel through the channel when the channel is restricted in width and depth relative to the ship's beam and draft.

1. Maneuver the vessel through port and starboard turns in a channel, changing ship's speed as necessary and using a bow thruster when the channel bends are:
  - a. Greater than  $90^{\circ}$
  - b.  $60^{\circ}$  -  $90^{\circ}$
  - c. Less than  $60^{\circ}$
2. Maneuver the vessel under a bridge structure using appropriate planning techniques (e.g., studying charts and publications). The following bridge conditions should exist:
  - a. Satisfactory horizontal and vertical clearance
  - b. Satisfactory vertical clearance but horizontal clearance is constrained by bridge support structures
  - c. Bridge is lighted
  - d. Bridge is unlighted
3. Time the maneuver for the opening of the bridge during different stages of approach when:
  - a. Opening time communicated is correct
  - b. Opening time communicated is delayed
4. Maneuver the vessel to remain on the intended track, when approaching and maneuvering into:
  - a. Two cross channels
  - b. Three or more cross channels
  - c. "Y" channel (junction)
5. Execute a starboard and a port turn into crossing and "Y" channels, projecting own ship's track.
6. Maneuver the vessel through a blind turn (i.e., visual and/or radar detection obstruction) in a channel when:
  - a. Other ship contacts are obscured by hills, trees, natural barriers, and manmade structures
  - b. Navigational aids are hidden until turns begins
  - c. Oncoming vessel creates a meeting situation
7. Maneuver the vessel in the channel and through various turns when forward vision is partially obstructed by ship structure or cargo (e.g., deck load stacking).
8. Conn the vessel through the channel with consideration for the following nearby obstacles located at various positions within the channel:
  - a. Dredges
  - b. Ships anchored adjacent to, or in the channel
  - c. Numerous small craft, sailboats, fishing boats, etc.
  - d. Vessels in tow
  - e. Buoy tenders
  - f. Work under construction
  - g. Ship not under command



- h. Cables and pipelines
  - i. Breakwater
9. Maneuver the vessel to avoid a shoal or a wreck in the vicinity of the channel entrance when:
    - a. Marked by a buoy and/or
    - b. Fathometer is inoperative and/or
    - c. Possible shoaling due to recent storm
  10. Maneuver the vessel through the ice.
  11. Maneuver the vessel to avoid navigating through ice.
  12. Maneuver the vessel through the channel without deviating from the intended track, when the navigational range structures available for various channel legs have:
    - a. A light extinguished
    - b. One or both range structures obscured, or
    - c. One structure missing.
  13. Maneuver the vessel through the channel when the navigational aids available for various legs of the channel are:
    - a. Extinguished
    - b. Off position
    - c. Missing
  14. Maneuver the vessel through the channel when natural fixed or navigational structures are:
    - a. Masked
    - b. Missing
  15. Maneuver the vessel into/out of the channel when a ship is anchored in the approach to the sea buoy and the radar reference sea buoy is off location.
  16. Communicate via ship-to-tugs using appropriate format and terminology to request tug assistance for channel maneuvering.
  17. Coordinate strategy to be used by tugs. Then communicate with the tugs as to the number of tugs needed and the placement of each.
  18. Coordinate the activities and maintain communication with the pilot and mate.
  19. Configure the vessel to facilitate tug assistance (e.g., ship speed). Coordinate vessel actions (e.g., rudder, rpm) with tug efforts to achieve objectives for normal situations.
- C. Approach a Single Point Mooring
1. Determine the approach bearings and the points at which to reduce speed and/or stop engines.
  2. Maneuver the vessel in the approach to the mooring, coordinating approach bearings and speeds, safely avoiding other traffic and other moored vessels.
- D. Approach a Dock
1. Determine the approach bearings and the points at which to reduce speed and/or stop engines, with tug assistance.

2. Maneuver the vessel with tug assistance in the approach to the dock, coordinating approach bearings and speeds, safely avoiding other ship traffic.

E. Approach and Anchorage

1. Select the appropriate courses and navigational aids to fix the ship's position en route to the appropriate anchorage, check the depth of the water at the anchorage, and locate the turning bearing.
2. Maneuver the vessel to approach the anchorage position, taking into account the location of other anchored vessels. Accomplish this maneuver under the previously determined conditions as well as under the following conditions:
  - a. Water depths of 100-500'
  - b. Various types of holding ground
  - c. One anchor/two anchors
  - d. Having way on/having no way on
  - e. Using remote sensors and pilot house control
3. Anchor the vessel. Once anchored, take cross bearings to fix position.

III. Emergencies

For emergency situations, the following conditions should be addressed in addition to the previously denoted conditions:

- a. Varying duration of failure
- b. Ship configuration
  - (1) Twin screw
  - (2) Single screw
  - (3) Controllable pitch propeller
- c. Various time lags for power response
1. Plan for emergency action alternatives prior to entering the harbor, based on the identification of relevant harbor characteristics. Carry out plans under the various harbor situations.
2. Anchor or ground the vessel clear of the channel to minimize casualty damage due to:
  - a. Loss of power
  - b. Loss of steering
  - c. Collision
  - d. Fire
3. Maneuver the vessel through the channel maintaining ship control as best as possible when each of the following types of rudder failures occur:
  - a. Loose rudder
  - b. Rudder jamming of mechanical systems
  - c. Partial loss of rudder
4. Safely maneuver the vessel when there is a degradation in the amount of power available, including complete power failure.
5. Maneuver the vessel through the channel when an electrical failure affecting ship control occurs in the following equipment:

- a. Rudder angle indicator
  - b. Radar (poor visibility)
  - c. Gyro
  - d. Engine order telegraph
6. Use tug assistance when a casualty (e.g., power and/or steering failure) occurs while underway to:
  - a. Moor or dock
  - b. Anchor
  - c. Otherwise assist in maintaining vessel safety
7. Detect, correct and/or compensate for the following ship control errors caused by ship's personnel and/or pilot:
  - a. Wrong command ordered on the EOT
  - b. Wrong command implemented by engine room
  - c. Helm put over the opposite way from that which was ordered
  - d. Helm put over by an improper amount
  - e. Depth sounding reported incorrectly
  - f. Position plotted incorrectly
  - g. Contact's course, speed, range, or CPA plotted and/or reported incorrectly
8. Maneuver the vessel through the channel when each of the following types of communication are inoperative:
  - a. VHF
  - b. Whistle
  - c. Running lights
  - d. Walkie-talkies
  - e. Internal phone systems
9. Maneuver the vessel avoiding any collisions when the following equipment are inoperative:
  - a. Radar
  - b. CAS
10. Configure the vessel to facilitate tug assistance (e.g., ship speed). Coordinate vessel actions (e.g., rudder, rpm) with tug efforts to achieve objectives for emergency situations.
11. Maneuver the vessel through turns in the channel when:
  - a. Rudder failure occurs
  - b. Engine failure occurs

#### IV. Team Coordination/Communication

1. Within the framework of set procedures which are situation dependent, each team member should perform parallel and serial functions in coordination with the other team members and in a timely manner.
2. Within the framework of set procedures which are situation dependent, each team member should transmit the required information to the appropriate source in a clear, concise, and timely manner, using the proper format and terminology.

## V. Bridge Procedures

1. Research tidal information, check charted characteristics of navigation lights and buoys against lists of lights and navigation bulletins, consider the ship's maneuvering characteristics, and check prevailing conditions; then organize port entry/port exit passage plans (preferred and alternate tracks) in detail so as to provide for full control of navigation. Organize the duties and pattern of communications of a bridge team so that the plan, once made will be executed properly, especially when the unexpected arises. Include alternative action contingencies for the development of unexpected situations.
2. Execute the plans during passages, incorporating alternatives as required.

These SFOs, which pertain to shiphandling, reflect the training needs of the master today. Fundamental shiphandling is addressed at several simulator facilities, while integrated shiphandling is addressed at several other simulator facilities. Bridge operating procedures, particularly in the form of the bridge team concept, is addressed at the simulator facility in Warsash, Southampton, U.K. Of particular interest is the finding that emergency shiphandling, one of the areas that appears to have the greatest potential for simulator-based training, does not appear to receive training emphasis at many of the simulator facilities. Emergency shiphandling has been emphasized during the experimental Valdez operational exercises at CAORF and at the Netherlands Ship Model Basin, with resultant demonstrable improvements in shiphandling skill.

The final set of SFOs represent those skills that may be feasibly trained on a shiphandling simulator. The cost/effectiveness of achieving each SFO via simulator-based training, however, has not been determined; it represents a goal of this project. Other additional skills required of a master have been deemed as inappropriate for training on a shiphandling simulator, and are not addressed by this set (see Appendix A).

The potential relative effectiveness of a shiphandling simulator was estimated for achieving each of the identified SFOs. The intent of this evaluation was to provide a comparison between simulator-based training and other available means of achieving the SFOs. A comparison of simulator-based training with experience was determined as inappropriate at this time, as a result of early discussions with the working group. Furthermore, the effectiveness of experience as a means of achieving each SFO is difficult to assess due to the wide variability in experience received by individuals. On-the-job training (OJT) was selected for comparison with simulator-based training, since OJT may be viewed as the at-sea counterpart of simulator-based training. An estimate of the relative potential effectiveness of each would yield useful information.

The potential effectiveness of OJT versus simulator-based training was estimated for each SFO. Objective information is not currently available for this evaluation, necessitating the use of subjective estimates. These estimates are viewed as preliminary, awaiting more definitive evaluations in later project phases. Nevertheless, they do provide meaningful comparative information. The estimates were made by several individuals in each of the major disciplines represented on the investigation team (i.e., psychology/training, simulation, and maritime operations). The final set of estimates represents a composite of the individual estimates.

Each of the SFOs was evaluated with regard to its potential for achievement via on-the-job training (OJT) versus on a simulator (Appendix A). Note that OJT does not refer to experience at sea, but to a structured training program to be conducted on the job at sea, presumably under the direction of the master or other designated personnel. At this point, training is not being viewed as a substitute for experience, but as a supplement. The

relative comparison of OJT versus simulator-based training was achieved in terms of five categories spanning "OJT Only" to "Simulator Only" (i.e., see the column headings in TABLE 3). The categorization of each SFO was based on several criteria: a) Safety (S), b) Cost (C), c) Simulator Limitations (SL), and d) Training Control (TC). Each SFO was evaluated with regard to relative differences pertaining to each criterion, yielding placement in one of the five columns for each criterion. The placement of each SFO in TABLE 3 reflects the composite of the four criteria, and represents the estimated relative potential effectiveness of that method. Placement of SFOs in the three middle columns denotes a preference, but does not reject OJT or simulator-based training. Placement of SFOs in the two extreme columns denotes that only one method is considered feasible.

Several points should be made prior to discussing TABLE 3. Safety was considered in terms of the degree of risk presumed associated with training the SFO by the method. Cost represents order of magnitude estimates on the overall cost to achieve each SFO; estimates are believed to be poorest for this criterion. Simulator limitations pertain to substantial deficiencies in the current level of maritime simulator technology, whether or not the technology is presently operating on a simulator. This criterion, furthermore, pertains to practical limitations on the characteristics and use of simulators, even if the technology is available. Training control represents the variety of considerations necessary to conduct an effective training program. These include, for example, (a) the capability to configure the scenario (e.g., creating wind magnitude and direction on cue, placement and actions of other vessels, and harbor configurations), (b) the capability to repeat precise situations rapidly, (c) flexibility in configuring the scenario and controlled series of scenarios, (d) the provision for appropriate diagnostic feedback information, and (e) the availability of effective training methodology and qualified instructors.

The method of evaluation may best be illustrated by an example. The SFO II.B.1. categorized as "Simulator Best", deals with maneuvering a vessel through turns in a channel (see Appendix A). If the mariner is receiving training in this SFO he presumably may not perform this skill adequately. The simulator context appears to present substantially less risk than the on-board OJT context for learning to maneuver a vessel through turns in a channel, particularly under the difficult situation and environmental conditions. This evaluation denotes that although achievement of the SFO II.B.1 via OJT may be acceptably safe, substantially less risk would be associated in its achievement via simulator-based training. Substantial differences in cost are not apparent; simulator technology is not significantly limited in achieving SFO II.B.1. Hence, these latter two criteria point to simulator or OJT. Finally, training control would be difficult to achieve in the OJT context (e.g., control of wind direction and speed during the turn), leading to a preference for the simulator. Two of the four criteria denote no difference; the other two criteria point to a preference for the simulator. Hence, SFO II.B.1 was placed in the "simulator best" category denoting a relative preference for simulator over OJT. The two criteria leading to this placement are indicated next to the SFO in TABLE 3.

The findings reflected in TABLE 3 were unexpected. Rather, a normal distribution of SFOs was expected centered about the center column. The data in TABLE 3 shows that the vast majority of SFOs have a greater potential for achievement on the simulator than by OJT, due to a combination of the above criteria. Simulator limitations appear to be the prime factors that would suggest that any of the SFOs could be better achieved via on-the-job training. Simulator training appears preferable for most SFOs on the basis of training control alone, since many of the necessary scenario situations would be difficult to set up at sea. Furthermore, cost factors would also preclude OJT for most SFOs. The cost of dedicating or diverting a ship for training purposes would be prohibitive on a large-scale basis. (This technique has been used in isolated instances; e.g., the Arco Fairbanks was dedicated to training for one month to enable individuals to obtain Valdez pilot

**TABLE 3. POTENTIAL FOR SFO ACHIEVEMENT: ON-THE-JOB  
TRAINING VERSUS SIMULATOR**

Category	On-the-Job Training Only	On-the-Job Training Best	Simulator or On-the-Job Training	Simulator Best	Simulator Only
I Fundamental Shiphandling		A3 (SL)		B1-3,5 (TC) (C) D1,2,3,5 (TC) (C) E1-3 (TC)(S)	A1,2,4 (TC)(S) B4C (TC) C1&2 (TC)(S) D4 (TC)(S)
II Integrated Shiphandling		B10 (SL)	D1	A1-14 (TC) B1-9(TC)(S) B11 (TC)(S) B14a (TC)(S) B15-19 (TC)(C) C1&2 (TC)(S) D2 (C) E1,2 (TC)(S) E3 (S)	B12&13 (TC)(S)(C) B14b(TC)(S)(C)
III Emergencies				1 (TC)	2-11 (TC)(S)
IV Team Coordination/ Communication				1 (TC) 2 (TC)	
V Bridge Procedures				1 2	

TC = Training control  
SL = Simulator limitations  
S = Safety  
C = Cost

endorsement.) Safety considerations, which are the most important, also suggest simulator training for most SFOs. Those SFOs placed in the "Simulator Only" category were done so on the basis of safety. It is unlikely that any of the SFOs in this category could be achieved via OJT, due to practical considerations. It should be understood that the SFO categorizations in TABLE 3 represent only those pertaining to the general area of shiphandling. This table, therefore, shows that shiphandling skills (SFOs) would be better achieved via simulator-based training, and some are likely to be achieved only in this manner. These findings represent a baseline estimate from which more definitive estimates should be developed. Additional information should be collected to substantiate these findings. Objective information should be the goal. More widespread subjective opinions, however, could be readily obtained until the objective information is generated.

Many deck officer SFOs exist in other areas for which OJT is likely to be preferable. Some areas of knowledge that would be better acquired from classroom instruction or an on-the-job training program include:

- a. Navigation and related skills requiring lengthy calculations or supplementary tables such as:
  - Celestial and great circle navigation
  - Star identification
  - Compass compensation
  - Chart corrections - aids to navigation
  - Fuel conservation
  - Weather forecasting - ship's routing
- b. Cargo storage and handling
- c. Stability and ship construction
- d. Areas of application, exceptions, authority, and penalties as applied in the Rules of the Road
- e. Rules and regulations for merchant vessels
- f. Laws governing marine inspection
- g. Use and maintenance of lifesaving equipment
- h. Ship sanitation - medical, health
- i. Ship's business/management
  1. Interface with shore personnel
  2. Port authorities
    - (a) Agriculture
    - (b) Immigration
    - (c) Customs
    - (d) Quarantine
  3. Company correspondence, requisitions
  4. Communications/radio - weather reports
  5. Dispensing of money (i.e., payrolls, vouchers, records)
  6. Personnel problems with unions, individuals
  7. Checking of routine reports
    - (a) Log books
    - (b) Weather
    - (c) Deck and engine abstracts
    - (d) Inventories

- 8. Ordering of tugs and pilots
- 9. Distribution of information to relevant personnel
- j. Pollution control

Formal on-the-job training under the direction of senior officers is not an established practice within current union guidelines or company policies. Informally some masters have initiated unstructured on-the-job study programs, but because of the rapid turnover of personnel from the union and ship/leave scheduling, an ongoing structured course of study would require extensive company/union planning and cooperation.

Approaches that may prove useful for on-the-job training include:

- a. Use of video tapes especially for delineating specific, current problems associated with cargo or safety and for presenting information on new trends and equipments.
- b. In-company qualification programs similar to programs currently used to qualify men in submarines. The goal of these programs would be to ensure that masters and mates are expanding their knowledge and skills concurrently with technological expansion and change in the marine industry.

The SFOs comprehensively address those skills that should be acquired by the master. The complete set does not necessarily represent the SFOs that should be achieved by any one training system. It is likely that individual training systems would be designed to achieve a subset of these SFOs.

A format was developed to categorize the SFOs on the basis of their importance to the safety of the vessel (i.e., the relative importance of the SFOs). Three categories were developed, as follows:

- a. Category 1
  - Ship readiness
  - Ship characteristics
  - Rote duties
  - Administration and/or organization
- b. Category 2
  - Routine maneuvering
  - Routine navigation
  - Internal casualty control (fire, flooding)
  - Routine ship traffic tracking and evaluating
  - Shiphandling in docking, mooring, and anchoring situations
- c. Category 3
  - External casualty control response (i.e., man overboard)
  - Maneuvering under adverse conditions
  - Navigating under adverse conditions
  - Rules of the road/collision avoidance
  - Operation of CAS under extreme conditions
  - Material failures.



TABLE 4 shows the distribution of SFOs according to these categories. The SFOs of greatest importance to be achieved by the master are in Category 3.

Simulator training should be provided for those SFOs for which simulator training is most necessary in comparison with OJT (TABLE 3) and for those SFOs that are of the highest safety category (TABLE 4). The combination of the information in TABLES 3 and 4 yields the priority of SFOs for simulator-based training. (See FIGURE 2.) The "High" priority was given to those SFOs in safety and category 3 for which the simulator was preferred. "Medium" and "Low" priorities were similarly assigned. Thus, FIGURE 2 illustrates the recommended priority of SFOs for simulator-based training. The training system should be designed to achieve the SFOs of highest priority. The system design should consider the achievement of the medium priority SFOs on a cost effectiveness basis. The low priority SFOs should be included in the system design only when cost effective to do so, and when their inclusion will not adversely affect the attainment of SFOs in the higher categories. Simulator and other training system component capabilities should be considered at this time with regard to their effectiveness in achieving the SFOs. This topic is addressed later with regard to the simulator and training program.

### 3.2.2 Skill Level and Abilities

A major conclusion, as noted earlier, is that different functionally stated skills are not generally required for the handling of different vessels. Rather, more importance should be attached to the level of performance of the skills as they differ between vessels and situations. For example, the maneuvering of very large vessels in channels that have not been altered often requires a margin of error less than that of a smaller sized vessel. The level of performance required for many skills may depend on the particular characteristics of the vessel.

The investigation into skills resulted in the identification of several underlying human abilities which may be directly related to vessel characteristics. These abilities may be fundamental to the proficiency level of the skills performed, and may be common to several skills. The abilities are basic elements of human perception and cognition. An ability has been conceptualized as a "broad capacity" underlying performance in complex skills and related to performance in a variety of human tasks (Fleishman, 1972). A skill on the other hand is more specific, defining the level of proficiency on a particular task. A skill thus can be made up of several component abilities. Examples of those identified during Phase 1 are listed below to give the reader a detailed impression of the distinction between abilities and skills.

- a. Instantaneous perception of the motion of an object (e.g., perception of the second hand moving on a watch, as opposed to the minute hand; perception of the vessel moving into the dock). A threshold exists for the perception of motion, in terms of minutes of arc per second, which is dependent on a variety of factors (e.g., lighting level).
- b. Perception of movement having occurred as the result of position change (e.g., change in position of the minute hand on a watch; movement of a vessel into the dock). Little is known about this ability.
- c. Perception of a position change; closely related to b above (e.g., the smallest movement of the minute hand that can be detected). A threshold exists below which the position change cannot be discerned.

**TABLE 4. SFOs CATEGORIZED BY SAFETY**

1 (Least Important)	2 (Medium Importance)	3 (Most Important)
I B 1-5	I C 1,2	I A 1-4
I D 1,2	II A 2-8	I D 3-5
II A 9-12	II A 13,14	I E 1-3
II E 1	II B 4,5	II A 1
	II B 11	II B 1-3
	II B 15-19	II B 6-10
	II C 1,2	II B 12-14
	II D 1,2	III 1-9
	II E 2,3	III 11
	III 10	IV 1,2
	V 1	V 2

(See text for category rationale.)

<b>Assigned Training Approach</b>	<b>Category 1</b>	<b>Safety Categories* Category 2</b>	<b>Category 3</b>
On job training only			
On job training best			
On job or simulator			
Simulator best			
Simulator only			
	<b>LOW</b>	<b>MEDIUM</b>	<b>HIGH</b>
	<b>Simulator Only</b> IB4	<b>Simulator Only</b> IC1, 2 III10	<b>Simulator Only</b> IA1, 2, 4 ID4 IIB12, 13, 14 III2-9, 11
	<b>Simulator Best</b> IB1, 2, 3, 5 ID1, 2 IIA9-12 IIE1	<b>Simulator Best</b> IIA 2-8, 13, 14 IIB4, 5, 11, 15-19 IIC1, 2 IID2 IIE2, 3 V1  <b>On Job or Simulator</b> IID1	<b>Simulator Best</b> ID3, 5 IE1-3 IIA1 IIB1-3, 6-9 III1 IV1, 2 V2

\*Refer to Appendix E, Section E.3 for an explanation of the categories. The range is from 1 (least important) to 3 (most important).

**Figure 2. SFO Priority For Simulator Based Training**

- d. Prediction of temporal events (e.g., the ability to predict temporal events as a function of the ship's reactivity to rpm and rudder changes). Both amount of time delay and magnitude of the vessel's reaction will affect this ability. The optimum time delay is about 2 seconds; performance typically degrades with time delays greater or less than 2 seconds (Leonard, 1954).
- e. Perception of acceleration and deceleration (e.g., the rate of change in the ship's velocity and turning rate). For example, the average person will perceive a change in the yaw motion when the velocity is doubled or halved over a 5-second period (Hick and Bates, 1950).
- f. The ability to determine orientation (e.g., vessel orientation relative to other vessels and the environment, especially in the absence of multiple environmental cues).

These abilities have been identified during Phase 1; other as yet unidentified abilities are also likely to pertain to shiphhandling. Little is presently known about human performance regarding these abilities, and particularly the factors that affect them and the types of effects. Many factors may affect the performance of masters regarding these abilities. For example, perception of the turning motion of the vessel may depend on the location of the wheelhouse in relation to the bow, the prominence of the jackstaff, the type of visual background and lighting factors, and the velocity of bow movement. Another important consideration is the effectiveness of training in improving these abilities, and the particular characteristics of the most cost effective training system in doing so. It is not known which abilities can be improved via training and/or experience. Discussions with masters and pilots suggest that each of the abilities can be improved, although the masters and pilots may rely on different abilities to achieve their high levels of skill.

Some information is available to suggest that these human abilities are fundamental to shiphhandling performance, since they may be directly related to the characteristics of different vessels. For example, researchers at TNO - Institute of Perception have suggested that shiphhandling performance may be directly related to the response lag of the vessel (e.g., time delay between giving a rudder command and the perception of the ship beginning to respond) (van Manen and Hooft, 1970). The basic research literature provides information to show that human performance in a variety of tasks is related to the time lag between operator action and system response. A time lag of 1 to 2 seconds is considered to be optimum, with human performance decreasing as the time lag increases above that value (e.g., Klemmer, 1956; Leonard, 1954; Rockway, 1954; Warrick 1949; and Woodworth and Schlosberg, 1954). This finding is clearly supported by applied design practice in the use of quickening and predictor displays to overcome the deficiencies associated with time lags. Their use for target tracking and submarine control by the Navy is one such example (e.g., Birmingham, Kahn, and Taylor, 1954; Kelley, 1962. J. D. van Manen and J. P. Hooft, 1970) suggest that time lags of greater than 4 seconds may significantly affect shiphhandling performance. (Note, they suggest that time lags of greater than 15 seconds are not unusual.) This example shows a relationship between ship characteristics and factors affecting human performance: (a) time lag as a ship characteristic function, is dependent on many design parameters such as rudder area and ship inertia, (b) time lag as a factor affecting a human ability, and (c) human performance as a function of time lag or ship characteristics.

Following the establishment of the relationships between ship characteristics, human abilities, and human performance, the effects of training and experience need to be determined. By identifying the abilities which are involved in shiphhandling, training techniques can be developed to improve skill performance by cultivating the abilities

making up complex skills. Another advantage is that low fidelity simulation has been shown to be quite effective for ability training. The training of abilities by employing a low degree of simulator fidelity has produced positive transfers to a variety of transfer tasks (Valverde, 1973 and Hogan, 1978). Several advantages may accrue from this approach. Low fidelity simulation can result in substantial cost savings. Furthermore, ability training, which is nonspecific training, allows for increased flexibility of personnel, since an ability is applicable to many skills. Personnel would be capable of transferring their abilities to a broad range of skills and, therefore, the utility of the individual would be enhanced. Lastly, necessary training in specific skills would also be reduced.

It would appear, based on the above reasoning, that shiphhandling training should focus on skill improvement by emphasizing relevant abilities. Considerable research is first necessary regarding human abilities and how they can be trained, particularly with regard to the training of deck officers. The issues would include, for example, (a) the identification of abilities, (b) the delineation of human performance as a function of factors related to ship characteristics and abilities, (c) the rate of learning via training versus experience, (d) the level of performance attainable via training versus experience, (e) retention and performance decay over time, and (f) the effectiveness of alternative training system characteristics for specific abilities.

### 3.2.3 Mariner Licensing Process

This task was not completed as originally planned (see explanation in Section 2.3.2). The present situation is summarized as it relates to the issues regarding the use of simulators in the training and licensing process.

The current licensing structure and practices were investigated with regard to the identified tasks, skills, and SFOs of the deck officer. First, it was documented that the licensing categories do not directly relate to ship characteristics affecting vessel handling, nor to the proficiency (i.e., skill levels or abilities) with which the licensee can handle the ship. For example, the present licensing structure for deck officers does not address itself to the problems which have emerged with the development of large ships of unusual handling characteristics. Rather, the license categories relate to other factors which, although important, bear no relationship to shiphhandling expertise. In the present licensing structure, licenses are granted based on:

- a. Whether the vessel is inspected or uninspected
- b. The vessel's tonnage
- c. Its horsepower rating
- d. The particular waters in which the vessel operates
- e. The type of propulsion system (steam, diesel, sail)
- f. The industry or type of activity in which it is engaged

The question which remains to be answered with respect to the present day licensing concept is: do the bases upon which licenses are granted discriminate between the skills and abilities necessary to handle varying types of vessels? To address such a question, a research program should be established to validate a structure of licensing categories on the basis of fundamental skill and ability concepts suggested by prior research. The licensing structure should be revised, retaining some of the present basis for granting licenses, but incorporating shiphhandling factors in the form of skill requirements. Tentative criteria, which as can be seen duplicate some of the existing criteria, are:

- a. The waters in which the vessel operates (close waters, coastwise, and open sea)
- b. The type of propulsion system (steam, diesel, single or twin screw)
- c. The type of industry or class of cargo being handled
- d. The handling characteristics of the vessel

A second factor is that mariners do not have a formal requirement to demonstrate their shiphandling proficiency prior to obtaining a license. The written test assesses shiphandling knowledge, but does not assess shiphandling proficiency. This practice is not responsive to changing maritime shiphandling problems or to governmental concerns. It is recommended that the issues surrounding the demonstration of shiphandling proficiency for licensing be thoroughly investigated. These include:

- a. Feasibility of testing on a simulator, including relevant simulator capability, cost, responsibility for financing the practice, amount of time, transportation costs, periodicity of retest
- b. Validation and effectiveness of simulator-based testing
- c. Training program-based skill demonstration leading to license

#### 3.2.4 Maritime Simulation

Simulation is heavily relied upon in several industries as a cost effective means for the acquisition and improvement of skill. Both the airline industry and the nuclear power generation industry rely heavily on the use of simulation. The operating situation in the maritime field, however, is different from that in either of the latter two industries. The pilot and reactor operator perform complex sequential tasks, usually procedural in nature, requiring a considerable amount of practice and skill. Simulation has been proven as the most cost effective alternative for procedural skill acquisition and improvement. On the other hand, a large proportion of the deck officer's tasks regarding shiphandling are not procedural; they appear more akin to decision-making, in which a predetermined sequence of timed actions does not typically exist. The value of simulation, and of the myriad alternative simulator characteristics, is unclear for this type of training.

Less than two dozen ship bridge simulators with a visual field exist worldwide. The characteristics of these simulators vary widely. Two major types are in use today. At Grenoble, masters learn shiphandling by operating scaled ship models on a lake. The remaining simulators use analog and/or digital computers to generate and control the simulation information, creating a shipboard environment in a land-based bridge. These latter simulators differ widely, however, in regard to their simulation characteristics and engineering design. For example, the visual scene may be black and white or color, have different visual fields of view and may be generated by a variety of different techniques. Hence, the relative effectiveness of the simulators is likely to vary widely as a function of the skills they are being used to train, and their other training system characteristics. Little objective information is currently available regarding the effectiveness of the different simulator characteristics (see the MARSIM '78 proceedings), although all simulators are, apparently, acceptable to the mariners being trained. The cost of the simulators, and hence the different simulator characteristics, also differ widely. The relative cost effectiveness of the alternative characteristics of ship bridge simulators (e.g., alternative fields of view) is generally unknown. This deficiency of objective design and use information represents a major area of needed research. A variety of research issues exist which may have a significant impact on training system design.

The state-of-the-art in maritime simulation technology is quite good, particularly with regard to the shiphandling simulator. The most obvious area of limitation, and that which typically represents the highest cost area, is the visual scene display. Several methods of visual display present a limited visual scene (e.g., nocturnal only display) at substantial cost savings. Other methods (e.g., computer generated imagery) attempt to re-create the complete visual scene, at a high cost. Each method has associated capabilities and limitations (see Appendix E for a listing of capabilities and limitations of the various methods). The visual scene also represents an area of rapidly developing technology, particularly in regard to computer generated imagery.

The current maritime simulators have many other limitations, typically owing to the particular methodologies used in each simulator subsystem. The capabilities and limitations vary between simulators. A comprehensive listing of capabilities and limitations associated with the various simulator subsystems and their alternative methods of approach is contained in Appendix E. Since the simulator is not the real-world, it is likely to always have limitations in the fidelity to which it represents the real world. The important consideration is not whether limitations exist, but rather the extent to which the limitations adversely affect the achievement of specific functional objectives via training. A further important consideration is the cost/benefit of simulator-based training in comparison with alternative methods of achieving the specific functional objectives.

The current maritime simulation technology state-of-the-art results in several operational limitations pertaining to shiphandling. The more significant limitations occur in the following areas:

1. Docking. The visual scene in most simulators, with the notable exception of Port Revel, does not have sufficient field of view below the horizontal to allow close-in docking maneuvers from the bridge wing. For example, the own ship's hull, the dock, and water between cannot be viewed when the ship is several feet from the dock. Successful docking has been accomplished to within 50 feet of the dock and right up to the dock with electronic docking aids. Although it is within the technological state-of-the-art to provide better visual scenery for docking, cost and demand considerations have dictated the current configurations. Ship dynamics have not been modeled for berthing at most simulators. These include, for example, time dependent mooring line and pier forces, thrusters effect as a function of the dock and other factors, and low speed water effects around a dock.
2. Shallow Water Maneuvering. The equations of motion for shallow water maneuvering have not been developed to the extent of deep sea maneuvering. Hence, shallow water effects (e.g., bank cushion, paddle wheeling, turning characteristics) have not been acceptably simulated on many of the simulators. Shallow water handling coefficients have been developed from ship design information and model tests, and are being implemented on simulators. However, the at-sea validation of these equations remain a problem. It should be noted that Port Revel can simulate shallow water effects by creating the appropriate environment; the ability to precisely control the environment (e.g., shape of an underwater bank), however, should present some difficulty.
3. Low Speed Maneuvering. The low speed dynamics of a vessel have presented modeling problems, particularly when the angle of attack is greater than  $20^{\circ}$ . Effects such as "kick turns" and "paddle wheeling" present modeling problems. These models are continually being improved as data is made available.

4. Tugs. The effect of tugs has been simulated on several simulators. However, much more needs to be done to comprehensively and accurately simulate the use of tugs (e.g., force rate, timing, effect of tug angles).
5. Wind and current. Sophisticated wind and current models are used by most simulators. However, considerable refinement is necessary to account for complex situations in which wind and currents interact with other factors (e.g., ship loading conditions, bank and bottom characteristics, cross current, passing ship). These are being developed and continually upgraded. Their validation at-sea, however, presents a problem.
6. Anchoring. Simulation of a single anchor that is holding well is accomplished on several simulators. The use of multiple anchors and the dragging of anchors is a current problem, particularly when own ship is turning.
7. Waves. The effects of waves have not been included in most land-based simulators, usually due to cost/benefit considerations. Land-based simulators usually provide 3 degrees of freedom rather than 6 (i.e., pitch, roll, and heave are not usually simulated).

The above list identifies several of the operational limitations of most land-based simulators, many of which are shared to varying extents by floating model simulators (e.g., Port Revel). Many of the limitations exist due to cost/benefit considerations and/or near-term technology limitations; the latter may be overcome in the near future if emphasis is placed in that direction. The predominant limitation of simulators from a long-term standpoint is the adequacy to which complex environmental interactions can be simulated. This limitation is not so much in the development of algorithms, but rather in their validation at-sea. The importance of any limitation should be determined with regard to the specific intended use of the simulator, and then compared with available alternatives on a cost/benefit basis.

The major simulator subsystems and their characteristics were identified, resulting in 12 major subsystems as listed below:

- |    |                 |                                       |
|----|-----------------|---------------------------------------|
| a. | Subsystem I.    | Visual Image Display                  |
| b. | Subsystem II.   | Visual Image Generation               |
| c. | Subsystem III.  | Radar/Collision Avoidance             |
| d. | Subsystem IV.   | Bridge Equipment Configuration        |
| e. | Subsystem V.    | Audio                                 |
| f. | Subsystem VI.   | External Factors                      |
| g. | Subsystem VII.  | Own Ship Motion Base                  |
| h. | Subsystem VIII. | Control Mode                          |
| i. | Subsystem IX.   | Facility Arrangement                  |
| j. | Subsystem X.    | Own Ship Characteristics and Dynamics |
| k. | Subsystem XI.   | Own Ship Malfunctions                 |
| l. | Subsystem XII.  | Training Assistance Technology        |

A variety of alternative characteristics were delineated for each subsystem, with evaluations of their respective capabilities and limitations. The alternative characteristics represent the range of characteristics of simulators in use today as well as those planned. It is likely that the effectiveness of these characteristics differs for different SFOs. Hence, each alternative characteristic was evaluated with regard to its capability in achieving each SFO (see Appendix E). This massive amount of data delineates the effectiveness of each alternative characteristic regarding the design and use objectives.



(i.e., particular SFOs) of the simulator and training system. These data, in essence, form the basis of the effectiveness evaluations. The relative effectiveness of color versus a black and white visual scene, for example, in the achievement of a particular set of SFOs, can be ascertained from these data. A simulator's effectiveness could be estimated and compared with alternative designs by: (a) identifying the particular subset of SFOs to be trained, (b) evaluating and summing the effectiveness of design alternatives for each subsystem regarding each SFO, and (c) making tradeoffs between the alternative characteristics on the basis of their effectiveness and cost. These data also represent the third criterion for the direction of simulator-based training. These effectiveness evaluations were primarily based on subjective judgments of experienced mariners and training specialists. Objective information can, and should be developed to more accurately assess the effectiveness of the alternative characteristics.

The cost of the alternative characteristics is a major factor to be traded off with their effectiveness. Some cost data were collected, indicating an extremely wide range for alternative characteristics. Most of the variance in cost among computer-based simulators is attributable to the visual scene, for which a variety of capabilities and techniques has been developed and/or proposed (e.g., nocturnal versus day and night, availability of targets during daylight hours, number of targets, computer-generated imagery, model board, film strip, and field of view). The cost data contained in this report are a sample of relative costs. The actual costs vary widely as a function of many factors, including technological development.

The issue of greatest importance is the relative cost effectiveness of alternative training system designs to achieve a particular set of SFOs. A methodology was developed to assist in the cost effectiveness evaluations, for both the simulator and training program elements of the system, to arrive at a final design. This methodology is based on the information generated in Appendices A, C, and E.

The analysis yielded findings that point to the potential applicability of both whole- and part-task simulators/trainers for the achievement of the set of identified deck officer SFOs. Part-task trainers that may be potentially cost effective include:

- a. Radar/navigation simulator -- for skills pertaining to collision avoidance, rules-of-the road, and navigation
- b. Other electronic systems (i.e., Loran or Decca, RDF)
- c. Shiphandling characteristics -- fundamental ship maneuvering
- d. Docking, mooring, anchoring

Each of these part-task trainers would address a subset of SFOs (see Appendix E, Exhibit E-6). Whole-task training on an integrated ship bridge simulator would be necessary to integrate the learned skills into a cohesive approach to shiphandling.

The combination of part- and whole-task simulators does not constitute a recommendation for training. Rather, it constitutes a recommendation for training research. The design of maritime simulators has been a subjective process, as evidenced by the widely varying simulator characteristics in existence today (e.g., see Appendix E, Exhibit E-1). They must differ in their training effectiveness, and most likely in their training cost effectiveness. Little objective information is currently available upon which to base design decisions. A large variety of research issues has thus, been identified pertaining to maritime simulator design (see Appendix E).

### 3.2.5 Training Program

Design of the training program should be closely integrated with the design of other elements of the training system. Those elements represented by the training program (see Section 1) are equal to the simulator in their impact on training effectiveness. In many cases the training program has a greater impact on effectiveness. Usually, the training program receives little emphasis in the simulator design process, and results in a less than optimally cost effective system.

Many training program issues are addressed in the appendices; several of which have already been mentioned. Several points should be stressed since they may have a substantial impact on the training system's design cost effectiveness. The literature substantially supports the methodological approach of part-to-whole task training, and individual prior to team training. Part-task training focuses in detail on a limited subset of skills, usually in an individualized training context. This type of training has been shown to be effective for specialized training in a narrow area. An example is training for the radar endorsement, which is considered a subset of shiphandling. This is viewed as part-task training for the master since it involves only a subset of the tasks the master would perform in the operational situation when on the bridge. Whole-task training, conversely, is concerned with the integrated functioning of the master while on the bridge, often in a team context. This type of training is directed toward a variety of task areas, including radar operation. Whole task training is typically used to provide advanced training in the operational setting (e.g., on a shiphandling simulator). Hence, part-task training is typically used to train the operation of one piece of hardware; while whole task training is used to train the integration of that hardware operation with other tasks to achieve system operation.

Relative to individual versus team training, the literature has indicated that the individual training of skills required for the accomplishment of a particular task objective, prior to training in the team context, is the most effective methodology for the acquisition of highly proficient team performance. That is, the training of individual skills is tantamount to the development of proficient team performance. In further support of this position, it has been found that team performance is not significantly disrupted if a highly trained individual is substituted for a team member.

Two other issues which are extremely relevant to the specification of the training program are training effectiveness and transfer of training. Training effectiveness refers to a change in the performance of the trainee when comparing pre- and posttraining exercises in the training situation. This is the first stage of validity which must be assessed by a training program. Transfer of training, on the other hand, refers to "performance validity" which demonstrates an improvement in on-the-job performance (i.e., at-sea shiphandling) as a function of the training program. This is a higher order stage in the establishment of validity.

Phase I addressed the training program structure, the framework within which simulator-based training could be implemented. Shiphandling training, as evidenced by the SFOs, covers a broad range of skills (i.e., maneuvering theory, normal collision avoidance and shiphandling, emergency shiphandling, and bridge operating procedures). Analysis of the input characteristics has shown that masters are likely to possess all of these skills at varying levels of proficiency. Hence, a shiphandling training program, particularly if it is integrated with the licensing process, will likely have to apply to individuals with widely differing proficiency in handling vessels. More importantly, an individual may be expected to enter training at almost any level of expertise. The training, particularly if it is required, would be very inefficient if it treated all trainees equally. The training program should be responsive to the individual needs of each trainee. The entering deck officer's time should not be wasted by receiving training in areas in which he is acceptably

proficient. It is therefore necessary to develop a training structure that will permit the tailoring of the training program to the individual's needs.

To meet this requirement, a modular training program structure is suggested. The SFOs were grouped in 12 modules, each representing a particular area of mariner shiphandling skill, as listed below:

- a. Rules of the Road
- b. Natural Forces Affecting Shiphandling
- c. Man-made Variations to the Environment
- d. Vessel's Mechanical Parameters as Related to Shiphandling
- e. Maneuvering
- f. Tug Assistance
- g. Mooring and Berthing
- h. Equipments
- i. Casualties
- j. Local Harbor Conditions
- k. Navigation
- l. Integrated Shiphandling

The modules may be treated as independent and self-contained units of learning, as if each module constituted a mini-course. A deck officer would undergo training in only those modules pertaining to his weak skills. This structure allows tremendous flexibility in the design and modification of training processes, the tailoring of training to the individual's needs, and the offering and scheduling of training modules.

Each module contains a detailed set of topic-level learning objectives, developed to achieve the respective SFOs. The modules and their content are not intended to be used directly for training. Rather, they provide a set of guidelines for the effective development of shiphandling training programs.

The deck officer's shiphandling skill could be diagnostically evaluated prior to entering training, to determine his strengths and weaknesses. A sample diagnostic analysis scenario is presented in Appendix D, Exhibit D-3. The diagnostic would be used to indicate in which subject areas the deck officer should receive training, if any. An example of this methodology is presented in FIGURE 3. Each column of the matrix represents the skills taught in a particular module. The level of skill proficiency, the vertical scale, ranges from low to high, with the acceptable level indicated by the upper horizontal line cutting across all modules. This acceptable level of skill represents the goals of the SFOs, and hence of the training program and individual modules. Shiphandling skill proficiency is necessary to be at the acceptable level. The input level, the lower horizontal line, represents the level of expertise at which training begins in each module. Deck officers must have skills equal to or surpassing this level to be qualified to enter the modules.

The administration of the diagnostic analysis scenario would result in a profile for each deck officer across the 12 modules, indicating the mariner's level of proficiency in each. An example is shown in FIGURE 3. Inspection of this profile shows the deck officer is weak in skills represented by modules 1, 3, 5, 6, 7, 9, 10, 11, and 12. He should receive training in each of these areas. Furthermore, he needs remedial training before entering modules 3 and 9. Finally, it is unnecessary for this officer to undergo training in modules 2, 4, and 8, since he surpasses the acceptable performance level in these. Further diagnostic breakdowns could be made within each module to more specifically indicate the



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training necessary. This structure thus enables the tailoring of training to fit the officer's particular training needs.

The actual application of training to overcome the shiphandling skill weaknesses would depend on many factors. Several different training facilities may offer training in one or more modules, scheduled at different times. The trainee would undergo training only in areas of weakness, scheduled in parts, when he has available time. This structure would allow a large degree of individual and institutional flexibility in the tailoring and scheduling of training.

### 3.2.6 Performance Measurement

A performance measure is a subjective and/or objective means of assessing the level to which a skill is performed. The performance measure would, for example, provide information pertaining to the master's shiphandling expertise and/or areas of shiphandling deficiency. The diagnostic evaluation and tailoring of training to specific needs is based on the availability of valid performance measures. Performance measures are also necessary for effective training to provide information feedback to the trainee regarding his behavior. Furthermore, the performance measures serve to establish validity and to determine the amount of training an individual needs to meet specific standards. The standards to be met are also established on the basis of a representative sample of performance scores obtained over the population of individuals who describe the characteristics that make up the trainee population. For example, a mate's or master's performance would be compared to performance standards derived from a representative sample of scores obtained from the constituents of the mate and master population.

A total of 76 performance measures has resulted from the Phase I analysis. These have been derived to indicate levels of shiphandling performance. They are based on both subjective and objective information. The particular measures appropriate for each SFO are suggested in Appendix C, Exhibit C-3. It should be noted that the set of performance measures represents a comprehensive listing of possible measures; considerable evaluation and refinement of each measure would be required prior to use.

The establishment of objective reliable performance measures regarding shiphandling is difficult due to a lack of problem definition relative to that which is to be trained. That is, lack of agreement exists as to the precise characteristics of good shiphandling. For this reason the performance measures presented herein are often dependent upon the specific task situations which make up each SFO. Validation of the performance measures will therefore be dependent upon specific problem definition. Each of the 76 performance measures suggested as a result of Phase I should be validated in terms of its sensitivity in describing the quality of performance. It is further suggested that a factor analysis methodology be imposed upon this large group of measures to determine which measures most accurately represent nonoverlapping, independent, skill and ability performance. Such a procedure will identify those groups of scores that represent specific skill performance as well as identify those measures which do not contribute to an accurate assessment of mariner performance. A factor profile may also be instrumental in developing the diagnostic analysis scenario to determine those skill and ability factors which are deficient and/or highly developed for each individual trainee. Additionally, it was found that of those performance measures that have been validated to date, few if any (with the exception of cognitive workload) are directly related to the perceptual information that leads to deck officer behavior. In short, research is needed that will relate specific vessel handling and motion characteristics to the specific perceptual information used by the deck officer, and finally to aspects of human performance.

Each of the areas with significant results pertaining to training system design has been discussed above, along with a summary of other findings. The Phase 1 effort was oriented toward the development of methodology and an information base upon which the design and use of maritime simulators could be evaluated.

## CHAPTER 4

### PHASE 1 PRODUCTS, CONCLUSIONS AND RECOMMENDATIONS

A wide variety of conclusions and recommendations has resulted from the Phase 1 effort. These pertain to many aspects of the training system and its development. The detailed conclusions and recommendations are contained in the appendices. The more important of these are summarized in sections 4.2 through 4.8. Section 4.1 lists Phase 1 products.

#### 4.1 PHASE 1 PRODUCTS

The products resulting from Phase 1 establish the foundation upon which the subsequent investigations will be made, and upon which the training system acceptance criteria will be developed. The products are completely described in the appendices and summarized below.

- a. Mate Behavioral Data Base (Appendix A)
  - 1. Comprehensive set of deck officer tasks -- based on the integration of tasks from several independent task analyses
  - 2. Characteristics of Port XYZ -- a comprehensive set of port characteristics which may be encountered by a vessel
  - 3. Casualty data -- synopsis of recent casualty statistics
  - 4. Comprehensive set of dock officer skills and knowledge
  - 5. Input characteristics for a master experienced in the handling of small tanker (i.e., 30,000 dwt), entering a training program for transition to a large tanker (i.e., 170,000 dwt). These represent those skills and knowledge the master possesses prior to training.
  - 6. Specific functional objectives pertaining to shiphandling -- a comprehensive set of detailed training objectives to be achieved by the master via training, either on-the-job or on a simulator
  - 7. Estimated importance of each specific functional objective with regard to vessel safety
  - 8. Estimated potential for achievement of each specific functional objective via on-the-job training versus simulator-based training; the criteria were safety, cost, simulator limitations, and training control
- b. Licensing Issues. These products will be included when this task is completed.
- c. Training Specifications (Appendix C)
  - 1. Review and summary of the state of the art of training methodology
  - 2. Fundamental human abilities related to shiphandling characteristics
  - 3. Information characteristics necessary to achieve each specific functional objective
  - 4. Training techniques applicable to the training of each specific functional objective

5. Performance measures potentially applicable to each specific functional objective
- d. Training Program Structure (Appendix D)
  1. Review and summary of the training programs in use of the ship bridge simulator facilities worldwide
  2. Detailed training program guidelines — twelve modules configured to enable the achievement of the specific functional objectives within the recommended structure; they present guidance in the form of detailed topic-level learning objectives and suggested classroom/simulator use to accomplish the necessary training
  3. Modular training structure — the modular structure includes provision for the diagnostic assessment (i.e., diagnostic analysis scenario) of ship handling skill and the subsequent tailoring of the curricula to the specific needs of the master/trainee
- e. Simulator Characteristics (Appendix E)
  1. Review and summary of the characteristics of ship bridge simulators worldwide
  2. Subsystems of a bridge simulator, including alternative characteristics for each subsystem
  3. Estimation of capabilities and limitations of the subsystem alternative characteristics
  4. Estimation of the relative effectiveness of each subsystem alternative characteristic with regard to the achievement of each specific functional objective
  5. Relative cost information for the subsystem alternative characteristics
  6. Methodology for directing the design and use of all components of the training system based on the cost effectiveness of the alternative characteristics that pertain to a particular set of specific functional objectives
  7. Recommendations for the investigation of part-task simulators
- f. Review and summary of the use of simulator-based training in the commercial aviation industry, and its relationship to mariner training (Appendix F)
- g. Review and summary of the use of simulator-based training in the nuclear power generation and industry (Appendix F)
- h. Phase 2 and Long-term Plan (Appendix G)
- i. Relevant research issues pertaining to mariner training and the use of simulators (contained in appendices A through E)
- j. Mariner simulator-based training system research and design methodology



## 4.2 TRAINING SYSTEMS APPROACH

The systems approach to training appears applicable to the investigation of simulation in regards to mariner training and licensing process. Both members of the maritime community and of other industries have suggested this approach. The Air Force, the Navy, and commercial airlines have all used it successfully in the design of simulator-based training systems. This proven approach views the training system as composed of SFOs, simulator(s), and a training program (i.e., including training methodology, curricula, and performance measures). This methodology should form the basis for (a) empirical investigation of alternative training system characteristics generating objective information in regards to their effectiveness in training shiphhandling skills; (b) design of mariner training systems (i.e., a part- and/or whole-task simulator coupled with a training program) developed on the basis of cost effectiveness tradeoffs among alternative system characteristics; and (c) design of sound simulator training acceptance criteria for use in allowing partial licensing credit. In the appendices a sample application of this methodology (selecting simulator characteristics based on subjective effectiveness information) demonstrates its feasibility.

The recommended methodology developed during Phase I emphasizes the identification of specific functional objectives, based on deck officer tasks and skills, to be achieved by the training system. The simulator and training program characteristics should be simultaneously designed, with tradeoffs made between them, to achieve a cost effective system with regard to attainment of the specific functional objectives.

Training in general, and simulator-based training in particular, should be viewed as part of the answer to the human performance problem facing the maritime industry. Training has capabilities and limitations which should be considered when deciding its use. Considerable research into all aspects of the training system is necessary to objectively define the capabilities and limitations pertaining to mariner training. Other factors to be considered in relation to human performance include: on-the-job training, at sea experience, motivation, personnel selection (i.e., at the academy entrance level and subsequently), vessel design, operating procedures, operating conditions, and ship equipment.

Elements of the training system (e.g., simulator and curriculum) should be designed on the basis of objective cost effectiveness information, of which relatively little currently exists. This information should be generated by empirical research investigating the training effectiveness of alternative training system characteristics. Furthermore, investigation into the transfer of training to at-sea behavior should be conducted to verify the training effectiveness findings and otherwise refine the approach to mariner training.

## 4.3 SKILL TRAINING

Based on information collected during Phase I, a broad range of shiphhandling skills is required of the deck officer. (See Appendix A.) Many of these skills apparently do not change as a function of vessel characteristics. The level of skill proficiency in handling vessels, however, does appear to change as a function of vessel characteristics. Furthermore, the skill proficiency appears related to fundamental human abilities which may be directly dependent on vessel characteristics, such as time lag in vessel response. The little information available clearly points to the importance of human abilities and their relation to vessel characteristics. The effectiveness of training "abilities" related to shiphhandling is unclear. It appears that skill training should place emphasis on the relevant abilities. Considerable research is necessary to (a) define the relevant human abilities and their relationship to shiphhandling skills, (b) define the relationship between

abilities and vessel characteristics, and (c) determine the effectiveness of training system characteristics in improving the level of human performance regarding skills and/or abilities.

Particular areas of initial research emphasis should be:

- a. Effect of time lag (i.e., response feedback) on performance (e.g., rudder and throttle).
- b. Effect of acceleration and deceleration rate (e.g., regarding turning, slowing, and increasing speed).
- c. Effect of informational cues regarding (a) and (b) above (e.g., relative location of wheelhouse (height and placement along ships centerline), visibility and use of jackstaff, information from the surrounding area).

On the basis of safety, cost, and training control, the simulator appears preferable to on-the-job training for most shiphandling skills. Those skills involved with emergency shiphandling (e.g., equipment failures) and difficult environmental conditions could not be practicably and safely taught anywhere except at a simulation facility. Furthermore, training control considerations also result in a recommendation to consider simulation for the training of shiphandling skills. The degree of control (e.g., action of other vessels), weather flexibility (e.g., sequencing of situations, repeatability of situations) and other characteristics (e.g., detailed feedback information) necessary for an effective training process either could not be accomplished or would be prohibitive on the basis of cost to accomplish at sea.

#### 4.4 SIMULATOR CHARACTERISTICS

A wide range of ship bridge simulator characteristics is currently available, both with regard to simulation fidelity and engineering design. (See Appendix E.) The varied characteristics of maritime simulators substantiate this finding. It is reasonable to conclude that the range of characteristics of current simulators also represents a range of training effectiveness and cost. Little objective information has been found in the literature pertaining to the effectiveness of alternative ship bridge simulator characteristics. Considerable research needs to be conducted to determine the relative effectiveness of the alternative characteristics, particularly in regard to the identified specific functional objectives.

Research into the effectiveness of simulator characteristics should initially investigate:

- a. The horizontal field of view —  $\pm 60^\circ$ ,  $\pm 120^\circ$ , or  $\pm 180^\circ$
- b. Color visual field versus black and white
- c. Night-only versus day and night visual scenes
- d. The need for, and number of, visual targets
- e. The richness/complexity and fidelity of the visual image
- f. The level of fidelity of the ownship equations of motion
- g. Interactive relationship between resolution, luminance, and contrast in the visual image

Part-task simulators are a cost effective means for providing specialized training in

several industries, including the maritime industry (e.g., radar simulator) (Zade, 1978). Their use should be investigated with regard to the training of subsets of the specific functional objectives. Many of the identified specific functional objectives may be achieved either partially or completely on a part-task simulator. Part-task training in particular should be investigated as a preliminary adjunct to whole-task training in the full bridge context. This approach to the shiphandling training system may prove to be cost effective for attainment of most specific functional objectives. Several part-task simulators are recommended for investigation, based on their potential cost effectiveness. These are:

- Radar/collision avoidance system
- Mooring and docking
- Ship characteristics
- Navigation

#### 4.5 LICENSING

Licensing categories and licensing practices appear to be deficient in that they do not consider shiphandling skill. Licensing categories, which address the vessel's horsepower and tonnage, are deficient in that they do not address the vessel's handling characteristics. Licensing practices do require an amount of experience, which may be interpreted as requiring a level of skill proficiency. However, a formal licensing requirement pertaining to level of skill does not exist. The quality of experience received at sea by individuals is likely to vary widely, with resultant widely varying levels of shiphandling skill. Demonstration of shiphandling skill should be a formal requirement.

#### 4.6 TRAINING PROGRAM STRUCTURE

The flexible and efficient use of the training system is of primary concern. A modular structure is recommended that will enable the flexible design and modification of shiphandling training curricula, and the tailoring of training to the specific shiphandling skill needs of each deck officer, or group of officers. (See Appendix D.) This approach, based on a diagnostic exercise, keys on the strengths and weaknesses of each deck officer to determine training emphasis. The modular structure, coupled with diagnostic evaluation and training program tailoring, is recommended for meeting the training needs of deck officers with divergent skills and knowledge.

The design and use of the diagnostic analysis scenario should be investigated to determine those aspects of performance that are most critical. This research should further develop the diagnostic analysis scenario as a valid instrument within the constraints of anticipated usage (e.g., time constraints).

A variety of research issues has been identified pertaining to the training program. These include the training structure, performance measures, and training emphasis on abilities; each of these has been addressed separately. Several training technique issues recommended for consideration in the Phase 2 investigation include:

- a. Mix of classroom and simulator time (e.g., positive guidance versus delayed feedback)
- b. Amount, context, and timing of feedback information

- c. Use of the simulator for group demonstration versus hands-on control during training
- d. Scenario level of complexity
- e. Specific harbor versus hypothetical harbor
- f. Short scenarios versus full-length scenarios

#### 4.7 PERFORMANCE MEASURES

Few adequate performance measures for the conduct of training have been developed or used. Much of this deficiency can be attributed to the current lack of precise definition of those characteristics that comprise good shiphandling. A variety of potential performance measures has been identified. Each of these should be validated with regard to its use for the specific functional objectives. A factor analysis of the set of measures is also recommended to determine the independent factors (i.e., composed of the measures) that relate to mariner/trainee performance. Furthermore, performance standards should be developed for each acceptable performance measure (relating to each specific functional objective) on the basis of the measure's application in training and/or empirical research. (See Appendix C.)

#### 4.8 PHASE 2

The analysis conducted during Phase 1 has concluded that little objective information is available for the design of ship bridge simulators to be used in the training of shiphandling skills. This analysis, furthermore, documented the information that is known regarding the various elements of the training system. The areas in which knowledge gaps exist were, as a result, identified in terms of recommended research issues. The recommended research issues are listed at the end of the appropriate appendices. The Phase 2 plans is presented in Appendix G.

#### 4.9 LONG-TERM INVESTIGATION PLAN

The schedule for a recommended long-term investigation plan to achieve the long-term project goals is shown in FIGURE 4. The figure illustrates the major areas of research and development as (a) the development of a feasible methodology and identification of important research issues; (b) the generation and compilation of an objective information base, via empirical research, for the design of cost effective shiphandling training systems; (c) the development of training program guidelines; (d) the development of training system acceptance criteria to be used by regulatory agencies for the evaluation of training systems; (e) the application of training to specific areas of mariner training needs (e.g., transition); (f) the investigation of the integration of simulator-based training into the deck officer training and licensing process; and (g) the application of simulation to other areas of mariner training and licensing.

The investigation plan recommends that the deck officer shiphandling problem be emphasized initially and that the technology and information developed be subsequently transferred into other relevant areas of mariner training and licensing. Furthermore, it is recommended that a long-term research and development effort be undertaken to (a) delineate the human ability/ship characteristic relationships and (b) develop information pertaining to the effectiveness of alternative training system characteristics. This effort



should begin with Phase 2. It should include the development of a comprehensive long-term experimental design plan for the coordinated investigation of important human ability/ship characteristic relationships, and simulator and training program characteristics.

The goal of Phase 2 is the development of objective cost effectiveness information pertaining to specific training system characteristics, generated from empirical research at CAORF. Characteristics of the simulator and other training system elements will be varied in a highly controlled manner to evaluate their effects on the training of shiphandling skills. A prototype shiphandling training program will be administered to experienced masters under the different controlled conditions.

It is recommended that the Phase 2 investigation concentrate on important issues affecting several different elements of the training system. The specific Phase 2 research issues should be selected from: (a) simulator characteristics (e.g., field of view), (b) training technology (e.g., positive guidance versus trial and error), (c) scenario design (e.g., complex situation versus simple situation, and (d) shiphandling skill groups (e.g., emergency shiphandling versus integrated shiphandling). The investigation of this range of variables will initiate the development of information pertaining to several of the important training system elements. Furthermore, it will provide an objective indication of the importance of interactions among the different training system elements. This latter area of findings will substantially impact the approach to be followed in later phases, as well as the training system design methodology.